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WORKSHOP APPLIANCES

INCLUDING DESCRIPTIONS OF SOME OF THE GAUGING AND MEASURING INSTRUMENTS, HAND CUTTING TOOLS, LATHES, DRILLING, PLANING, AND OTHER MACHINE-TOOLS USED BY ENGINEERS

BY

C. P. B. SHELLEY

Member of the Institution of Civil Engineers; Fellow of King's College, London and Professor of Manufacturing Art and Machinery

REVISED AND ENLARGED

EIGHTH EDITION

SCRAPING A METAL SURFACE

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PREFACE.

THE favourable reception accorded both at home and abroad to the previous editions of 'Workshop Appliances,' coupled with the demand for a new issue, have decided the Author upon now undertaking its revision throughout. In doing this he has endeavoured, by shortening the descriptions in some instances, and in others by substituting for them diagrams or drawings—the 'Alphabet of the Engineer,' as the latter have well been called—to find space for a larger amount of new matter than the mere addition to the number of pages would indicate.

The few original paragraphs relating to steel have been expanded into a supplementary chapter, containing several illustrations, which—like the generality of the engravings throughout the book—have been carefully engraved by Mr. G. Pearson, from photographs or original drawings.

It is hoped that these alterations will render the book more complete and more useful both to students and to workmen. The latter have frequently borne gratifying testimony to its value, and have made various suggestions to the Author, which have not been overlooked in the revision. In return he

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would impress upon them—equally with those upon whom devolves the responsibility of directing them—that competition with foreign countries is daily becoming keener, and that we can only hope to maintain our position in the race by constantly endeavouring to improve.

Students who may be inclined to regard as trivial the details which they will find described in the following pages should, as before, be reminded that it has not unfrequently been by attention to such apparently trifling matters that eminent Civil Engineers have achieved their successes.

The thanks of the Author are due to the members of many eminent engineering and other firms, several of whose names appear in the text or on the engravings of the machines of which they have kindly supplied photographs or drawings. But he must here express his indebtedness to Messrs. Smith, Beacock, & Tannett, and Messrs. Greenwood & Batley, of Leeds; to Messrs. Maudslay, Sons, & Field, Messrs. John Penn & Son, Mr. Ralph Tweddell, Mr. Calderwood, of Price's Patent Candle Co., Messrs. L. Sterne & Co., of London; and to Mr. E. Reynolds and Messrs. S. Osborne & Co., of Sheffield. Also he must again express his thanks to his friend Mr. A. L. Newdigate, for his assistance throughout the revision, and more especially in connection with the additional chapter.

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WORKSHOP APPLIANCES.

CHAPTER I.

ON MEASURES OF LENGTH, AND METHODS OF MEASURING.

It has been truly said that 'the most important step in the progress of every science is the measurement of quantities.' Progress in the mechanical arts is also greatly dependent upon measurement, or at least upon that branch of the subject which deals with lineal quantities. The course of our endeavours to arrive at accuracy in the practical determination of such measurements will be briefly traced in the present chapter.

Lineal measurement necessitates the use of some *Standard*, or Unit of Length, a necessity which must of course have been felt from the earliest times. But until the seventeenth century—at about the commencement of which some demand for increased accuracy seems to have sprung up—various natural objects served the purpose sufficiently well. Many of the names which survive to the present day show the origin of the measures to which they are applied. Thus we use the 'foot,' the 'hand,' and the 'nail,' for the expression of various small dimensions; whilst the 'cubit' (or forearm) and the 'pace'—though the former is not to be met with now—have in past times served

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to express somewhat greater ones. It was doubtless an advantage to make use of units, with duplicates of which every workman or trader was provided ; but inasmuch as they all vary to a great extent in different individuals, they could obviously only be used for measurements of the roughest description. Attempts were made long ago in this country to secure one permanent unit, or standard of length, and although they have been successful as far as commercial and other practical ends are concerned, the history of our endeavours to obtain one sufficiently invariable for scientific purposes is a standing example of the uncertainty of human undertakings.

Some of the old statutes enact that three barley-corns, round and dry, make an inch, twelve inches a foot, three feet a yard, &c., and there seems to be no doubt that this mode of obtaining the standard was actually resorted to. But, setting aside the objection due to the varying sizes of individual grains—unless the average from a very large number of them be taken—it is so difficult to know how much of the sharp end of a grain of barley must be removed in order to make it 'round,' that the definition is not of much value. Nevertheless, in spite of numerous attempts at legislation on the subject, this, down to the year 1824, was the only process by which the standard yard of this country could, if lost, be legally recovered.

In the year 1742, when the Royal Society took the matter in hand, there were several standards of length in existence, which, although they were not recognised by law, served the purpose of approximately regulating the measures used for commercial and other purposes. A careful comparison made by order of the Royal Society showed considerable variation between them ; so from the most reliable of them a clever mechanician named Graham (to whom we owe the mercurial pendulum, and several other improvements in clocks and watches) was employed by that Society to mark off the true length of a yard upon a brass rod. From this

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—the first standard worthy of the name—a Parliamentary Committee caused a copy to be made in the year 1758 by an optician named Bird, who was also afterwards employed to make a second copy. These two standards were duly placed in the hands of the Speaker of the House of Commons, but a Bill to constitute the first of them the national standard was not carried ; so there they remained. Another Committee appointed in 1790 did nothing, and the matter was then shelved till the year 1814.

During this interval, however, not only did several private individuals and learned societies provide themselves with standards, but scientific men turned their attention to devising means for the recovery of the national standard—if it should ever be lost or destroyed. Accordingly a Committee in 1814, after recommending the adoption of Bird's standards, defined the British yard as consisting of thirty-six inches,—the length of a pendulum making one vibration per second being 39·13047 of such inches. In 1819 a Commission was appointed by the Prince Regent, which in that and the two following years presented three Reports. In the first Report the length of the seconds' pendulum, and also the weight of a cubic inch of distilled water, were stated ; but in the second and third Reports respectively both of them were altered,—the former to 39·13929 inches, the latter to 252·458 grains, —under certain stated conditions. These Reports resulted in the Act of 1824, by which Bird's standard of 1760 was at length legalised.

Only ten years after this, in 1834, the fire occurred which destroyed the Houses of Parliament, and with them both of Bird's standards ; so the country again found itself without an authorised copy of its standard of length. It might naturally be supposed that recourse would at once be had to the pendulum, and that the easy and speedy restoration of the lost standard would be the result. But this was not the case ; and a Treasury Commission appointed in 1838 declined to recommend that method, serious sources of

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error in the former experiments having been subseqnently discovered. Fortunately, however, the Royal Astronomical Society had, only two years before the destruction of the Houses of Parliament, caused a standard to be made for its own use, and this had been most carefully compared with the Parliamentary standards. From it, therefore, taken in conjunction with other reliable copies, the Commissioners (whose Report was presented in 1841) recommended that accurate Parliamentary copies be made, by the careful preservation of which the true length of the British yard should be perpetuated, in preference to depending upon experiments for obtaining it from any natural constants whatsoever.

Acting on this Report, the Government appointed a Committee to carry out the recommendations contained in it, under which was commenced a series of experiments and investigations which are almost, if not altogether, without parallel for the care and perseverance bestowed upon them. Those connected with the restoration of the standard of length—with which alone we have to deal—were begun by Mr. Baily (to whose assiduity the Astronomical Society owed its standard), and after his death in 1844 were carried on by Mr. Sheepshanks. The delicacy of their operations may be gathered from the fact that a change of temperature of only one-hundredth part of one of Fahrenheit's degrees was found to produce a sensible effect in the length of a bar; a quantity which at that time no thermometers in the country were capable of registering. Therefore, in addition to accurate determinations of the rate of expansion in different metals, careful comparisons of the most trustworthy copies of the standard, and many other points to which time had to be devoted, new thermometers of immensely increased accuracy had to be devised and constructed. To this arduous task Mr. Sheepshanks gratuitously devoted the last eleven years of his life, dying on the very eve of its completion, in 1855. What remained to be done was undertaken by Mr.

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(now Sir George) Airy, till lately Astronomer Royal, to whose memoir in the 'Philosophical Transactions' for 1857 the reader who is interested in the subject will do well to refer for further details of the work.

The result of their joint labours was the adoption of two of the existing copies of the lost standard, one of which was henceforward to be regarded as *the* standard. From this four 'Parliamentary copies' were made, of which No. 1 was deposited in the Royal Mint, No. 2 in the keeping of the Royal Society, No. 3 in the Royal Observatory at Greenwich, and No. 4 was immured in the lower waiting-hall of the Houses of Parliament.[1] In form they are all solid bronze bars, 1 inch square, each being 38 inches long. Near the ends of each bar there are two holes, in which are inserted gold plugs with fine lines engraved upon their surfaces, which lines are exactly one yard apart, at a certain stated temperature. An Act legalising them was passed in 1855, since which date—despite the efforts which have been made in this country to implant the mètre with its decimal system—these bars have continued to be the only legal source from which all our measures spring, and the real safeguard against the loss of our national unit, the British yard.

In addition to the length of the second's pendulum, other natural standards have from time to time been proposed. Such are, the velocity of light, the length of an undulation of a ray of light of definite refrangibility (neither of which are practically available), and various dimensions of the earth itself. One of these has been adopted by the

[1] Subsequent alterations at the Houses of Parliament have rendered necessary the removal of this Parliamentary copy, together with those of the Standards of Weight, &c., which were immured with it; the wall in which they were originally placed having been pulled down in order to form an entrance to the refreshment rooms. The *Times* (of March 21, 1872) states that 'On the 7th of March . . . the standards were deposited in their new resting-place in the wall on the right-hand side of the second landing of the public staircase, leading from the lower waiting-hall up to the Commons' Committee rooms.'

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French, whose unit of length, the mètre, professes to be one ten-millionth part of a line drawn on the surface of the globe from the pole to the equator. The length of this line was deduced from measurements of the arc of the meridian between Dunkirk and Barcelona. The result of these measurements, which were commenced in 1792, has since been found to be incorrect by an appreciable quantity, and the length of the mètre, if once lost, could with no greater certainty be recovered from any natural standard than can the British yard. Consequently the decree passed by the French Republic in 1795 wisely defined the mètre to be the distance between the ends of a standard bar of platinum, without reference to the source from which it had been derived. Borda determined the exact relation which the length of this bar bears to that of a pendulum vibrating seconds in the latitude of Paris, but the true safeguard against the loss of the French, as of the English, standard lies in the preservation of accurate copies of the bar by which it is represented.

The length of the standard mètre at 62° Fahrenheit is 39·37079 British inches, which for practical purposes may be easily remembered as *three feet three inches and three eighths of an inch*, this being only ·00421 (about $\frac{1}{240}$) of an inch in excess of its true value. Some further information concerning the French standard, and the connection which exists between the units of length, capacity, and weight in the metric system, will be found in the volume of this series on 'Heat,' by the late Professor J. Clerk Maxwell, and also in that on 'Inorganic Chemistry,' by the late Doctor W. A. Miller. Where large numbers of weights or measurements have to be converted from the metric to the British system, or *vice versâ*, time and trouble may be saved by laying down contiguous scales of equal parts, bearing the proper proportion to each other—on the principle of the 'Metric Scales,' by Mr. A. L. Newdigate, recently published.

It was proposed by the late Sir John Herschel to adopt

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the earth's polar axis as a fundamental unit of length. For this purpose it might be considered to contain 500,500,000 (five hundred million five hundred thousand) British inches, which is not more than 82 yards (about $\frac{1}{170000}$) in excess of its true length.

In the restoration of the standard yard, the means employed for detecting the minute differences of length which had to be dealt with, consisted of a pair of microscopes attached to a perfectly firm foundation, in the focus of each of which were placed two intersecting cross-hairs. A slow traversing motion could be given by means of a micrometer screw, the head of which was so divided that each graduation represented a movement of one twenty-thousandth part of an inch. The comparison of two standard or other scales was effected by accurately adjusting the points of intersection of the cross-hairs over the lines engraved upon one of the scales, then replacing it by the second scale and again adjusting the micrometer screw, the graduations on the head of which registered the difference in the length of the scales.

This method is known as 'line' measure, or *mesure à traits*, in contradistinction to *mesure à bouts*, or 'end' measure. In the former, as we have just stated, the length is given by the distance between two fine transverse lines drawn upon the standard bar, and it is read by the aid of micrometer microscopes, with which the limit of accuracy practically attainable has been found to be one fifty-thousandth of an inch. In the latter it is given by the distance between the ends of the bar itself, which is placed in actual contact with the instrument by which it is measured; and Sir Joseph Whitworth has shown that for this purpose the sense of touch is much more reliable than the sense of sight, inasmuch as minute distances can be enlarged with much greater certainty by mechanical than by optical means. On this principle he has constructed machines capable of detecting a difference of one-millionth part of an inch in the

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length of two bars; and he considers that with the assistance of these there would be no difficulty in producing any required number of copies of the Parliamentary Standard, each one of which would be quite sufficiently accurate for all ordinary purposes of reference, so that the wear and risk of injury to the original standard would be reduced to a minimum.

Four views of a machine of this kind are given in Fig. 1, p. 11, and some particulars relating to it can scarcely fail to interest the reader. It must be borne in mind that its object is not to make an original measurement of the total length of any bar, but to compare it in the most accurate manner possible with a nearly similar standard bar of which the exact length is known, and to record, to the millionth part of an inch, any difference which may exist between them. The particular machine here represented is constructed to receive a bar only one inch long; but one made upon a precisely similar principle, which was capable of taking in a bar forty inches in length, was shown in the Great Exhibition of 1851, and obtained the award of the Council Medal for Sir J. Whitworth, to whose courtesy we are indebted for the photograph from which the 'General View' has been engraved. Another machine for 'end' measurement was also exhibited there by the Prussian astronomer Bessel.

The appearance of the instrument will be evident from the General View which stands at the head of the page, whilst the outline Plan, Section, and End Elevation below will explain its construction—the same parts being indicated by the same reference letters in all of them. A standard one-inch bar (D) is there shown in position for being measured—or rather for being compared with some other bar. A rigid mass of cast iron (A) forms the bed of the machine, the casting being carried up at each end so as to form two headstocks. Running from one of these headstocks to the other is a V-shaped groove, in which the square bars B and C are laid, and which also receives the

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standard or other bar (D), of which the length is to be tested. The sides of the groove, and also those of the bars (which are square in section), are worked up as truly plane as possible, and are kept accurately at right angles to each other, so that, upon whichever sides the bars may rest, they are capable of sliding smoothly and with perfect steadiness in the groove. Their ends also are carefully made square to their sides, and are brought to true planes; one extremity of each, in the case of B and C, and both extremities of D, being turned down, so as to present circular instead of square faces. Through each headstock runs an accurately pitched micrometer screw, by which B and C can be driven forwards along the groove; as may be observed in the left-hand portion of the Plan, in which the saddle by which B is protected and partially concealed, when the machine is in use, has been removed. The screw on this side, which has exactly 20 threads to the inch, is made to advance or recede by turning the wheel F, the circumference of which is divided into 250 parts. Consequently, by turning the wheel forwards through one division, the bar B is moved through $\frac{1}{20} \times \frac{1}{250} =$ one five-thousandth of an inch. The other screw, which likewise has 20 threads to the inch, is driven by a worm-wheel of 200 teeth, into which gears a tangent-screw, H, having fixed upon its stem the graduated wheel G. The circumference of this wheel being also divided into 250 parts, a movement through one division corresponds to a traverse of $\frac{1}{20} \times \frac{1}{200} \times \frac{1}{250} =$ one-millionth of an inch on the part of bar C. Fixed pointers enable the exact distance through which either of the wheels F or G is moved to be read off, so that we have thus the means of detecting this extremely minute difference in the length of any bars,—if, at least, we can fulfil the important condition of causing the micrometer screws to exert a perfectly equal pressure in every case. The arrangement by

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which this equality of pressure is secured is one of very great simplicity and beauty. Between one extremity of the bar under comparison and the sliding bar, a small steel plate with truly plane and parallel sides is introduced. This plate is called the 'feeler' or 'gravity piece,' and its ends (E E) are drawn out so as to rest upon two supports fixed upon the sides of the bed. When little or no pressure is exerted upon the bar D, the feeler, if one of its ends be momentarily raised from the support, falls back again by its own weight; when, on the other hand, the pressure is at all considerable, it is either incapable of being raised without violence, or, when lifted, does not return; the friction, in fact, between its own plane surfaces and those of the bars between which it is placed forming a delicate measure of the pressure to which they are subjected. When this pressure is just sufficient to keep the feeler from falling by its own weight, without interfering with its perfectly free motion when touched, the correct adjustment has been given to the instrument.

Suppose now that a proposed duplicate is to be compared with a standard one-inch bar. The standard (D) and the feeler (E E) are first placed in the positions shown in the figure, contact between them and the sliding bars being nearly established by turning the wheel F; after which the final adjustment is given with the wheel G. As soon as the feeler, on its end being lifted, remains suspended instead of falling back upon its support, the adjustment is known to be complete, and the position of the wheel G is accurately noted. Since the new bar is to be an exact copy of the standard, the coarse adjustment wheel F is left untouched, the standard being released by moving the wheel G only, which is again adjusted when the duplicate of which the length is to be tested has been laid in the groove. If the position of the wheel then prove to be the same as before, it is evident that the length of the bars is identical; but if not, the exact difference between them is given in millionth parts of an inch by the number of divisions by which the second

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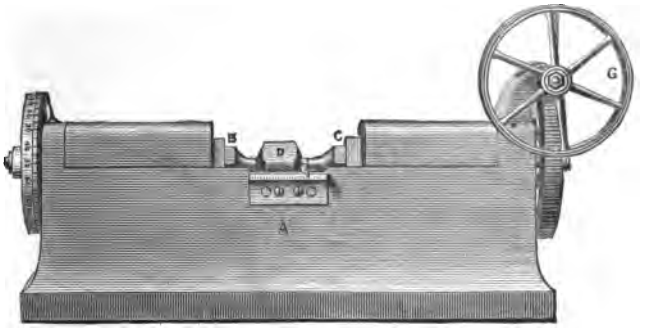
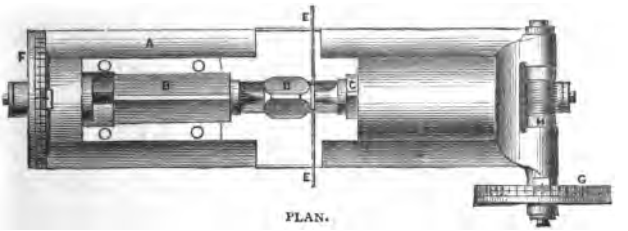
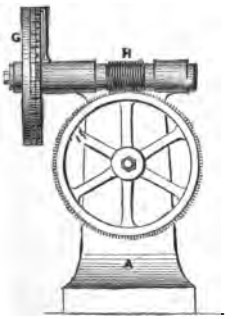


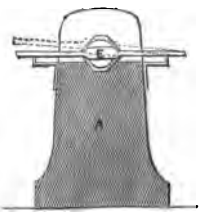
GENERAL VIEW.



PLAN.



END ELEVATION.



SECTION.

FIG. 1.—Whitworth's Millionth Measuring Machine.

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reading differs from the first; a movement through one of these divisions being sufficient to release the feeler or again to arrest its fall when the adjustment of G is correct. This degree of delicacy will thus be seen greatly to surpass that of the measurements which have been obtained by reading line measures with the aid of powerful microscopes. As an instance of the extreme sensitiveness of machines of this kind, it may be mentioned that by taking due precautions for the exclusion of dust, moisture, and currents of air, a difference of one two-millionth of an inch—corresponding to half a division on the fine adjustment wheel—has been rendered distinctly perceptible, so that it has been possible actually to measure the expansion produced in an iron bar by touching it for an instant with the finger. Indeed, the expansion with every slight increase of temperature constitutes the only difficulty with which Sir Joseph Whitworth has now to contend, and he is of opinion that 62° Fahrenheit, which is adopted in this country as the standard temperature, is too low for the purpose, since, if it were increased to 70° or 80°, its uniformity would be much less liable to disturbance from the warmth of the operator's body. But it must not be supposed that this acme of mechanical precision is by any means easy of attainment. For it is obvious that if the slightest want of uniformity of pitch were to exist in the micrometer screws, or if the sides of the bars, &c., were not extremely close approximations to true plane surfaces,—their ends being at the same time accurately at right angles to the common axis of the bars and screws—it would have been impossible to arrive at the wonderful degree of accuracy which can now be obtained with these instruments.

For expressing the minute fractions of an inch which these instruments enable us to measure, as well as for measurements generally, whether theoretical or practical, in which very small subdivisions of the unit employed must be taken into account, it is admittedly preferable to have

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recourse to decimal rather than vulgar fractions. Unhappily, opinion is somewhat divided as to the unit upon which such subdivision should be based. Advocates of the metric system urge its adoption, on the ground that it is a system complete in itself, which would facilitate our transactions with France and other countries in which it is used, and would do away with much of the labour now expended in computing by means of our British weights and measures. On the other hand it is held,—that decimal subdivisions by no means necessitate the employment of decimal multiples of the unit, which, for convenience in most of the transactions of everyday life, are greatly inferior to those now in use; that the length of the mètre is inconveniently great for a standard unit, and as far as its value is concerned, as being one even theoretically perfect and recoverable, we should by no means be gainers by its adoption; also that immense practical difficulties stand in the way of our making so radical a change, which would entail, during many years, the endurance of the evils of a mixed system over a large proportion of the globe. These and other reasons, which it would carry us too far from our subject to detail, leave, indeed, no doubt that the disadvantages involved in the adoption of the mètre, or any other new standard, would much more than counterbalance the advantages. The retention of the inch as *the* unit for the purposes of the mechanician, with the simple substitution of decimal for the ordinary or 'binary' subdivisions in all cases of fine measurement, provides us with the means of recording dimensions with any required degree of minuteness, and, so far from provoking the opposition which the attempt to implant an entirely new system would encounter, it has already made great progress towards general adoption.

Turning now from the consideration of the terms in which our measurements are expressed, to the practical means employed for their determination, the first thing

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which claims our attention is the Measuring-rule. Fig. 2 represents the form most commonly employed by mechanics, which consists of a strip of box or lance-wood 2 feet in length, jointed at the centre, so as to enable it to be carried in the pocket. Each 12-inch length is often further jointed so as to reduce the total length, when folded, to 6 inches, these being known as 'four-fold' and the other as 'two-fold' rules. They are divided throughout into inches, half-inches, quarters, and eighths—sometimes also into sixteenths—below which it is not customary to carry these binary subdivisions (*i.e.* those obtained by dividing and subdividing by 2). For although these are more convenient than any others for ordinary rough measurements, the higher denominators, such as 32, 64, 128, &c., are, in this respect, inferior to decimals for the expression of minute quantities, as has already been pointed out. At the back of these rules there is frequently a brass slide, 12 inches long, which is marked with inches on its interior and with logarithmic scales on its exterior surface. The former are useful for enabling the workman to measure the depth of a groove or cavity; but he is seldom at the pains to make himself acquainted with the latter, though a few simple lessons in it would teach him that he carries in his pocket many hundred times as much power of calculation as he has in his head. The cheap rate at which these rules are sold is the only excuse for their usual inaccuracy. But various other forms of rule, made of wood, ivory, and metal, far too numerous for mention here, are to be found at every tool and instrument maker's shop; of which—as is the case with most other articles—the price generally regulates the quality.

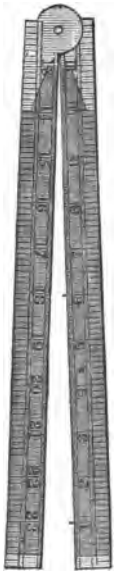

FIG. 2.
Two-foot Rule.

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Larger dimensions, when required but roughly, are most readily taken from a measuring tape. To obviate the tendency of linen tapes to stretch, steel ones have been introduced; but for accurately setting out long lengths they are never likely to displace the simple expedient of using a pair of deal measuring rods, each of the exact length of 5 or 10 feet, which are alternately placed end to end the requisite number of times. For still greater lengths as in measuring land, &c., the surveyor's chain either of 66 or 100 feet is exclusively used—but this does not come within our present subject.

With straight and inflexible measuring scales or rules, however, it is evident that many of the dimensions which are required in the workshop cannot be obtained directly. This is true of almost all cylindrical forms, as well as of many others of frequent occurrence, the most simple method of determining the size in such cases being to apply to the inaccessible portion of the work a pair of *callipers*, which ordinarily consist simply of two curved steel legs (Fig. 3), stiffly jointed together after the manner of a pair of compasses. The points of these are set to such a distance apart that they are just able to pass freely over the cylinder or other article to be measured, its diameter or thickness being then found by laying the callipers upon an ordinary rule. It will be observed that the pair shown in the engraving can be used not only for outside dimensions but also for inside ones, provided that the size of the aperture is sufficient to admit them. Two other forms of plain callipers will be found represented in Chapter V.; and yet others are made, amongst which may be mentioned *sliding callipers*, in which the pivoted joint is dispensed with, and a graduated sliding bar substituted. These, which somewhat resemble the sliding gauge, Fig. 10, are 'contact'

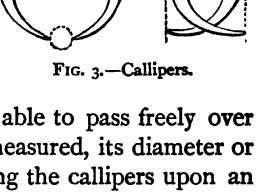

FIG. 3.—Callipers.

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measuring instruments of considerable delicacy, and are not open to the charge of inadequacy for any but rough measurements. This, on the other hand, may justly be urged against callipers of the ordinary kind, which, although tolerably satisfactory correspondence between two pieces of work may be obtained with their assistance, are of comparatively little use for determining their true size. To do this entails the conversion of the end or contact measure, which is expressed by the distance between their points, into the line-measure marked on a scale or rule—a task by no means easy even in the case of rough measurements, and one which, when scientific accuracy is necessary, becomes a serious difficulty.

It may be mentioned in passing that the following is the principle upon which this can be correctly done. Two end-measuring bars are taken, of which the length is equal, or the exact difference of length known, and a line is drawn across each, at or near the centre; their ends are then placed in contact with each other, and the distance between the lines is read with a pair of microscopes, such as are used for line-measure. Both bars are then turned end for end, and the distance between the lines is again read; the mean of these two readings gives the mean length of each bar.

Since, as we shall hereafter see, all workshop measurements except those of an approximate character are obtained by some form of contact measure, the difficulty of this operation forms a strong argument in favour of the dissemination of end-measure copies of the standard, by which private measuring instruments may be verified when necessary. This step has for many years been advocated by Sir Joseph Whitworth, and its desirability has now been recognised by the Board of Trade. Legalised 'Secondary Standards,' and sets of 'Plug and Collar Gauges,' such as we shall presently describe, have been deposited in London at the office of the Standards Department. Copies of these

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are there verified, free of charge, for any Local Board in the United Kingdom which is sufficiently enlightened to take this simple step towards insuring accuracy in the measuring instruments used throughout its district.

'Mural Standards' have also been set up in Trafalgar Square, with which rules, tapes, or measuring chains of any of the following lengths can be tested with sufficient correctness for ordinary purposes:—One foot, two feet, one yard, sixty-six feet, and one hundred feet.

One case of everyday occurrence for which graduated rules and other 'line' measuring instruments cannot be successfully used, either directly or with the aid of ordinary callipers, is the measurement of the diameter of a wire. Another is that of the thickness of a sheet of metal, which it is generally necessary to ascertain with much greater nicety than would be possible with a measuring rule, even if its graduations were sufficiently fine.

For such cases common practice bears testimony to the superiority of 'contact' measure to 'line' measure by adopting the simple contact instruments which are known by the name of *Wire* and *Plate Gauges*. Of these the *Birmingham Wire Gauge* (a common form of which is shown in Fig. 4) may be taken as the prototype. Parallel-sided notches of various widths are cut round the edges of a steel plate about $\frac{1}{8}$ of an inch in thickness, each notch being distinguished by a numeral; the series in Fig. 4 running from No. 1 to No. 26. The 'number' of a wire is ascertained by merely trying which notch (if any) is just sufficiently wide to allow it to pass. So far the system is satisfactory enough. Very small variations from the intended sizes can be detected, and the instrument itself is neither costly nor too delicate for common use. Two things only are wanted to make it fulfil all ordinary requirements, viz.:

FIG. 4.
Birmingham Wire Gauge ($\frac{1}{2}$).

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a sufficiently extensive series of 'numbers,' unanimously agreed upon, and always designated by the same numerals; and the reference of each number to some recognised standard, so as to guard against the possibility of its loss or gradual alteration. In both of these respects all the gauges which were formerly in use are lamentably deficient. In the 'B.W.G.' (by which letters the Birmingham Wire Gauge is distinguished) the numbers form an arbitrary series, which for many purposes has proved itself quite insufficient. Various other gauges, equally objectionable in their method of designating the sizes which can be measured by them, have accordingly found their way into use; and as no sort of correspondence exists amongst them, there results an amount of confusion and complication from which the only chance of escape seems to be in their total abolition.

Careful comparisons have more than once been independently made with a view to ascertaining what standard value could be assigned to the various numbers of these miserable systems, but entire agreement has not been and probably never will be arrived at, since gauges which profess to be alike are found to differ amongst themselves, and there exists no authoritative means of correcting them. It is therefore earnestly to be hoped that the whole of them will gradually fall into disuse and be replaced by some complete and easily recoverable series of numbers, such as that of the *Standard Decimal Gauge*, of which the adoption has been urged by Sir J. Whitworth since 1857. The 'numbers' of this gauge—of which the main portion, reprinted with his subsequent corrections, from his 'Miscellaneous Papers,'[1] will be found in the Appendix, represent the actual sizes expressed in thousandth parts of an inch. By this simple alteration several gaps are filled up, so that we are enabled to gauge sizes for which the old gauges had

[1] *Miscellaneous Papers on Mechanical Subjects.* By Joseph Whitworth, F.R.S. Longmans, 1858.

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no numbers, and in addition to this we are relieved from the inconvenience of having the same size expressed by two or more different numbers, which was frequently the case before. As an instance of it we may mention that No. 36 of the Decimal gauge represents the following numbers in five of the old gauges :—No. 20 of the Birmingham Wire Gauge ; No. 13 of the Birmingham Plate Gauge ; No. 62 of the Lancashire Gauge ; No. 18 of the Music-wire Gauge ; and No. 3 of the Needle-wire Gauge ; the size in each case being ·036 of an inch.

Wire gauges occasionally take other forms than that of a steel plate with parallel-sided notches, such as Fig. 4. A single tapered opening may be substituted for the whole series of notches, the 'number' or 'gauge' of the wire being found by passing it down the opening as far as it will go, and reading the number opposite to it on the graduated edge. Wire gauges of this kind are known as V-*gauges*, and they are capable of giving the diameter of round wire with a fair amount of accuracy, even when as small and compact as the upper one of the two represented in Fig. 5. They can-

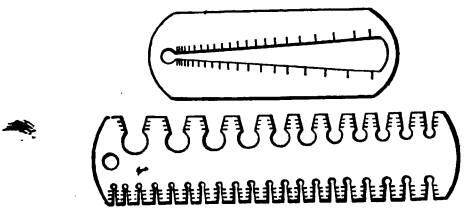

FIG. 5.—V-Gauges.

not, however, be used for gauging sheet metal, nor for any wire that is not circular in section.

A modified form of V-gauge, proposed by Mr. Hughes, is shown in the lower half of Fig. 5. The taper of the V being made very slight, with a view to obtaining increased accuracy, the inconvenience which would result from its

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great length is obviated by breaking it up into a number of separate parts, so that in general appearance this gauge strongly resembles those with the ordinary notches. The accurate manufacture of V-gauges is a matter of considerable difficulty, but they certainly possess the advantage of enabling the amount to be observed by which a wire exceeds, or falls short of, its intended diameter; and by graduating both sides of the V, they afford a ready means of comparing together the 'numbers' belonging to two different series,—as, for instance, those of the Decimal gauge and the Birmingham Wire Gauge.

The following particulars with regard to the gauges, of which the distinguishing numbers (or a portion of them) are given in the Appendix, may be useful.

The first column gives the numbers of the Decimal gauge, which progress by regular steps, and in all cases represent the actual size, as already stated.

In column 2 is the entire series of the Birmingham Wire Gauge, from No. 0000 to No. 36, with one exception (No. 0). In the gauges for ordinary use (as in that represented in Fig. 4), the first four and the last ten sizes are generally omitted, the total number of notches being thereby reduced from 40 to 26. This gauge is much more extensively used than any of the other arbitrary gauges—wire (with some exceptions), sheet iron, and steel, and frequently also other sheet metals, being referred to it.

In column 3 will be found most of the numbers of the Birmingham Plate, or Metal gauge. Whenever the thickness of sheet metal—with the exception of those mentioned below—is expressed by an arbitrary number, this series is presumed to be referred to, although the numbers in the previous column, with the affix 'B.W.G.,' are not unfrequently substituted for them. Even when the lower numbers of the Plate gauge are used, the series is often considered to end at No. 24, the larger sizes being then borrowed from the previous column. Since the numbers of these two

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gauges run in opposite directions, the whole arrangement is well adapted for producing confusion.

Column 4 contains many of the numbers and letters of the Lancashire gauge. Commencing with No. 80, which coeresponds with No. 29 B.W.G., this gauge absorbs all the numerals down to No. 1, following them up with the whole alphabet from A to Z; after which, still unsatisfied, it recommences with A1, B1, &c., till it reaches its maximum, H1 (=·494, or nearly half an inch). It is used for pinion wire, and for round *bright* steel wire; 'Music wire' and 'Needle wire' being exceptions which have distinct and separate gauges of their own. 'Rope wire' and 'watch-spring wire' are also similarly favoured.

Among sheet metals the following are the principal ones which are not referred to the Birmingham Plate gauge :—

1st, Sheet iron and steel, as already mentioned.

2ndly, Zinc, which, being chiefly rolled in Belgium, has a gauge of its own, which we give in the Appendix; sheets of greater thickness being referred to the B.W.G. numbers, although these run in the reverse direction.

3rdly, Lead, which is estimated by the number of pounds per superficial foot, advancing generally by single pounds from 4 lbs. to 12 lbs.

4thly, Copper and Brass, which, when in large sheets measuring 4 feet by 2 feet (containing therefore 8 superficial feet), are described by the number of pounds in a sheet. The thicknesses of 5-inch and other narrow widths of rolled brass, copper, &c., beyond the range of the Plate Gauge, are generally expressed by the numbers of the B.W.G.

5thly, Tin plate; which is not referred to any gauge, being sold in boxes bearing special marks, which indicate the number of sheets contained in each, their weight and size. A table giving these will be found in the Appendix.

Lastly, Plates of iron or steel exceeding 1-8th (=·125) of an inch in thickness, are specified by the number of inches and binary divisions of an inch being rolled (in

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ordinary cases) to eighths, sixteenths, &c. This enables the weight of any wrought-iron plate to be easily calculated by applying the useful rule which teaches us that—Rolled iron weighs 5 lbs. per superficial foot for every eighth of an inch in thickness.

Another example of contact-measuring instrument, and one which is to be met with in every workshop in which the accurate measurement of cylindrical work of moderate size is frequently required, is to be found in the case-hardened cylindrical gauges, of which an example is given in Fig. 6. To enable these gauges to be used for measuring both internal and external diameters, they are made in pairs, being called respectively *External* and *Internal*, or *Plug* and *Collar*, *Gauges*. Provided that they are correct in the first instance, no more ready or more certain method of testing cylindrical work can be conceived,—their simplicity of form and ample strength being for practical use a very high recommendation. But each gauge can, of course, only be used for the particular size to which it is made, so that a very large number of them is generally required. Indeed, a complete set of these gauges is an important item in the first outlay upon a fitting shop. Consequently an original set of standard gauges seldom is, and never should be, used, except for the production and correction of duplicates, the latter only being handed over for the use of workmen. But even when a full complement of these gauges has been provided (of which an ordinary set rises by either 10ths or 16ths for the first inch, by 8ths for the second, thence by quarters up to 6 inches —beyond which they are not usually made) uneven dimensions will be frequently found to occur, for which they render no assistance. In these cases a measuring machine, such as that shown in Fig. 11, will be found

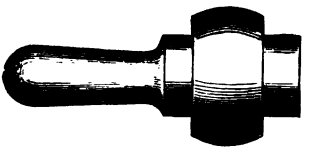

FIG. 6.—External and Internal Gauges.

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to be a most valuable adjunct, as it enables the number of standard gauges to be greatly reduced, whilst at the same time any intermediate dimensions can be easily and accurately obtained.

FIG. 7.—Stepped Gauge.

By grouping together the successive numbers of a series of external gauges, so that about 8 of them are formed in one piece, their cost is considerably reduced. Thus modified, they are known as *Stepped Gauges*, one of which is represented in Fig. 7; but they are obviously of more limited application than the gauges last described, and the smaller amount of cylindrical surface devoted to each dimension renders them liable to more speedy deterioration. Moreover, as they are not usually provided with collars, they cannot be used for outside measurements.

The cylindrical gauges would be too delicate if made smaller than one-tenth of an inch diameter, so that for sizes below this, down to one-hundredth of an inch, *Flat Gauges* are made, one of which is shown in Fig. 8. The two faces

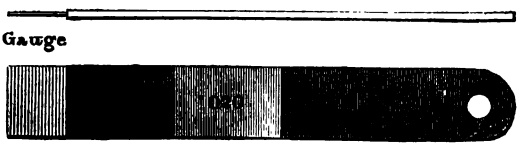

FIG. 8.—Flat Gauges (full size).

of the gauge are made true parallel planes. In the manufacture of the wire gauges described above, Flat Gauges of this kind, made to the exact width of the notches, are invaluable for checking their correctness.

Before, however, proceeding to describe the measuring machine just alluded to, it will be well to call attention to one or two delicate but very portable instruments, which, although they are not often to be met with in a workshop at

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present, might be more extensively used there with great advantage, as they are capable of rendering valuable assistance to a careful workman.

The simplest mechanical means by which minute quantities can be rendered visible would probably be an arrangement by which the forward motion of a sliding wedge should be made to record every slight increase in its thickness, and instruments on this principle have been proposed by Mr. Ramsbottom. Their magnifying power, as it were, depends upon the amount of 'taper' given to the wedge; for instance, a wedge 10 inches long and 1 inch maximum thickness would have a sliding motion of 1-10th of an inch for each 1-100th of an inch by which its thickness varied. A modification of them has been used in the locomotive engine shops of one of our large railway companies; the wedge being bent into a circle of about 10 inches circumference. Each complete revolution corresponds to a variation in its thickness of 1-4th of an inch, so that 1-1000th of an inch can be measured by causing it to revolve through about ·04, or 1-25th of an inch, which is a distinctly visible quantity. In most cases, however, this instrument cannot be directly applied to the work, and measurements must be made through the intervention of callipers.

Fig. 9 is a half-size drawing of a pocket instrument, which is quite equal to the foregoing in respect of delicacy of measurement, and is superior to it in convenience. As ordinarily made the screws have 50 threads to an inch, their heads having 20 divisions on the circumference. Each division therefore corresponds to a longitudinal motion of 1-1000th of an inch on the part of the screw; but this by no means represents the limit of delicacy which can be obtained on this system. It should be noticed that any slight error

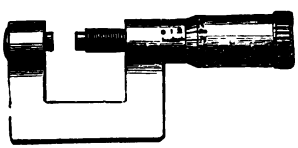

FIG. 9.—Thousandth Gauge (½).

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in the number of threads per inch which there may be in the screw can be corrected in graduating one of these instruments by recording the number of its revolutions on a spiral line, instead of on one parallel to its axis. The milled portion of the head is sometimes provided with an independent 'Breguet' motion, which obviates any tendency to put too much or too little pressure on the article which is being measured.

Another form of instrument, which may be carried in the pocket, is shown—also half-size—in Fig. 10. The scale A is marked with inches, which are divided into fiftieths. By means of the vernier B each fiftieth can be divided into 20 parts, the distance between the inside knife-edges of the

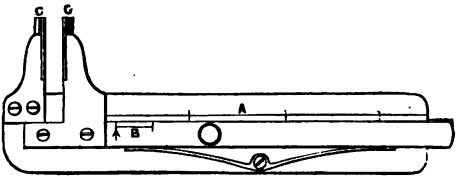

FIG. 10.—Sliding Thousandth Gauge (½).

jaws C C being thus read off to the thousandth part of an inch. These jaws being each made exactly 1-10th of an inch wide for a portion of their length, they can be used to some extent for inside dimensions, two-tenths of an inch being in this case added to the reading given by the scale. Either this or the previous instrument can be used for all the purposes to which the complicated wire and plate gauges above mentioned are applied, and for many others in addition.

But for verifying working copies of gauges—for insuring the accuracy of the various templates or patterns of size which are in daily use in the workshop—for maintaining constant uniformity of measurement, so that perfect agreement shall obtain between any articles of the same dimen-

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sions, even though produced at distant periods of time ; for all these, and for many similar purposes, the measuring machine, with a brief notice of which we will conclude this chapter, leaves nothing to be desired. It has been specially designed by Sir Joseph Whitworth for workshop use, and, as the great importance of accurate measurements in machine work becomes more and more generally appreciated, it will doubtless be found to be an increasing necessity therein.

The reader who has followed us through the description of the millionth measuring machine (Fig. 1), given at a previous page, will be able, without assistance, to understand the general construction and method of using the less delicate instrument of which Fig. 11 is a perspective view. We shall

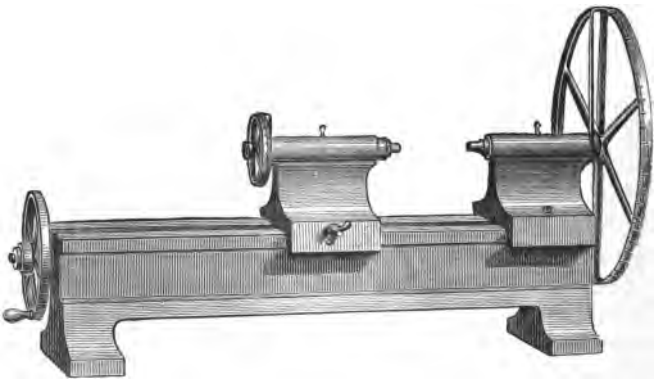

FIG. 11.—Machine for Measuring to the Ten-Thousandth part of an inch.

perhaps, therefore, best describe it by calling attention to the chief points in which it differs from the previous machine. In the first place, let us call to mind the difference in the duties which each of them has to perform. With regard to delicacy of measurement, their respective requirements are as far removed from one another as is the accuracy demanded of a scientific standard from that which suffices for commercial purposes ; so that whereas in the one case it is of

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the greatest importance to be able to record the most minute quantities—we have seen how the millionth part of an inch can be rendered visible, and, if it were possible, it would doubtless be desirable to take into account yet smaller fractions—in the other it is useless to provide the means of measuring distances, of which it is at present impossible for us to take cognisance in mechanical handicraft. On this account this latter machine is provided with graduations, each of which corresponds only to one ten-thousandth part of an inch. But the principal differences in its appearance are due, not to this diminution in magnifying power, but to the necessity for enabling this machine to admit articles of greatly varying size and form; since, if it could be applied only to measuring the length of bars of one particular section, it would be of comparatively little use in the workshop. On this account the headstocks, which in Fig. 1 are cast in one piece with the bed of the machine, are here separate castings; one of them being fixed at the end of the bed, the other capable of being moved to any part of it, and clamped there. The bed bears much resemblance to that of a small turning lathe, as also does each of the headstocks to the poppet, or sliding headstock, by which the back centre is supported. This movement of the headstock, which is effected by turning the small wheel at the left-hand side of the figure, rotation being thus imparted to a quick-threaded screw within the bed, enables the ends of the sliding bars to be placed at one foot or at any smaller distance from one another, whilst—owing to the height at which they are supported above the bed—a cylinder of as much as six inches in diameter can be brought into position for measurement between them.

The graduated portions of the instrument are three in number—in the first place the inches from 1 to 12 are marked upon the surface of the bed, so that the moving headstock can at once be approximately placed at the required distance; secondly, the small wheel carried by this headstock

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has 250 divisions round its circumference, each complete revolution of this wheel corresponding to a backward or forward movement of one-twentieth of an inch on the part of its sliding bar (that being the exact pitch of the screw to which it is attached); and lastly, the large wheel of the fixed headstock has 500 graduations upon its rim. The screw to which it is attached having also 20 threads to the inch, rotation through the space of one of these graduations causes the sliding bar in this case to move through $\frac{1}{20} \times \frac{1}{500} =$ one ten-thousandth part of an inch. The capabilities of this machine will thus be seen to be far more extensive than those of the other and the more sensitive instrument, and, although its performance may be less calculated to excite surprise and admiration, it is far better adapted to the fulfilment of every-day requirements. In using it standard bars and cylindrical gauges are of course required; this, like the former, being intended for making comparisons rather than original measurements. But, as we have before pointed out, a small number of carefully kept standards only are necessary, since intermediate steps in the series can be readily filled up, owing to the facilities which the graduated wheels afford for increasing or diminishing, within considerable limits, any dimension which has been accurately obtained from a standard bar or gauge. In the comparison of bars a simple form of support for them between the headstocks is desirable, since a 'feeler' can then be used in the manner already pointed out; but in the case of cylindrical gauges, or portions of work, the operation can be easily effected without such assistance, the gauge or other article being merely held in the hand and passed between the ends of the sliding bars, in the manner shown in Fig. 12. When the true adjustment has been given to the machine it has been found that an alteration of one forty-thousandth of an inch in the distance between the bars causes a distinctly perceptible increase or decrease in the resistance which the cylinder encounters in passing between them. Large gauges,

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&c., which are too heavy to be conveniently held in the hand, may be suspended vertically over the machine ; the adjustment can then be given as correctly as in the case of the very smallest articles.

A frequently recurring example, which will serve well to illustrate the use of this machine, occurs in fitting together two portions of a piece of work—such as a wheel upon an axle. If it be required to revolve, the diameter of the bear-

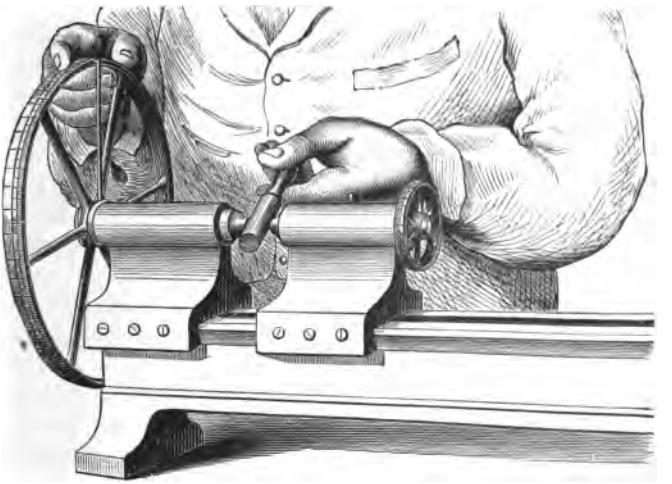

FIG. 12.—Testing Cylindrical Gauge with Measuring Machine.

ing must be somewhat larger than that of the axle ; if to be driven on so as to fit tightly, the diameter must be somewhat smaller. For either purpose the best result is obtained only with one particular amount of difference between the external and internal diameters ; and when once this has been ascertained, it should always be adhered to for the future.

Difference Gauges render it easy to maintain this correct proportion. Let us take the case of a wheel which is to

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revolve upon an axle 3 inches in diameter. For this a clearance of ·003 (three thousandths) of an inch will give good results under ordinary conditions,—though the amount should depend, amongst other things, upon the lubricant which is to be employed, as will be mentioned hereafter. A difference gauge of which the diameter exceeds that of the standard 3-inch gauge to which the axle will have been worked will therefore be required, so that the wheel boss may be bored out to it, and so a proper fit be secured with certainty. The accuracy of this gauge will be tested thus:—The moving headstock of the machine having been clamped at the 3-inch division on the bed, its wheel is adjusted till the 3-inch standard gauge can just pass freely between the ends of the sliding bars; the largest wheel upon the fixed headstock having been previously set to 0, or zero. This wheel is then moved through 30 divisions, which gives the exact difference required in the distance between the sliding bars. Contact with their ends on the part of the proposed 'difference gauge' then proves its correctness.

One-thousandth of an inch is sufficient to make all the difference between a good fit and a bad one, and although it might be thought that so trifling an amount could be disregarded in practice, it cannot be too strongly urged that it is by careful attention to such small details in proportioning and finishing the working parts of machinery that the best results in its performance can alone be arrived at.

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CHAPTER II.

ON HAND-TOOLS FOR CUTTING WOOD.

CUTTING-TOOLS, to which our attention must be chiefly confined in the remainder of the present volume, do not readily lend themselves to classification. Hand-tools and machine-tools are tolerably distinct from one another, though between these even it is not always easy to draw the line; but the subdivision of either of these main groups, except in some incomplete or arbitrary manner, presents considerable difficulty.

It has been proposed, for instance, to divide hand-tools into three classes, viz. paring- or splitting-tools, scraping-tools, or shearing-tools, the distinguishing feature of each class being the angle between the two faces, the intersection of which forms the cutting edge (or what is ordinarily called the *thickness* of the edge), taken in conjunction with the inclination at which the tool is applied. And although this suggestion by no means helps us out of the difficulty as regards classification, these distinctions being neither complete nor even satisfactory as far as they go, there is nevertheless something to be said in favour of their threefold division. For it indicates the three distinct processes by which—or by the combination of which—edge-tools do what is required of them in removing portions of the materials under treatment, all of which processes are ordinarily included in the term 'cutting.' These are—1st, by splitting or cleavage (as with an axe), which can only be done when the substance offers less resistance to separation in some directions than in others; 2ndly, by what may be regarded as true cutting, *i.e.* forcibly separating or dividing the particles in any desired direction independently of the natural structure of the substance; 3rdly, by sliding or tearing it

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apart without having recourse to cleaving (*e.g.* as in shearing). For the first of these but little is required of the so-called cutting edge but that it shall be of a suitable wedge form,—the angle of the wedge varying considerably according to circumstances. For the second, we must not only have a wedge-shaped edge of adequate strength and hardness, but also, either forming part of the cutting-blade itself or independently of it, there must be some means of directing and limiting the action. In many of the examples which will be given, one face of the cutting edge itself forms the requisite guide; in others, a series of such edges rigidly connected together one behind another serves a similar purpose; and in others again, the guiding surface is formed upon the handle or support to which the cutter is attached. Chisels, files, and planes may be taken respectively as instances of these. Lastly, the essential peculiarity of cutting-tools of the third kind is their being always in two parts, one of which is incapable of acting without the other.

But in attempting to classify the very miscellaneous instruments which are, or might be, included amongst cutting-tools, not only must the above differences be kept in view, as well as the inclination at which each tool is applied (and this we believe to have more to do with the distinction between 'paring' and 'scraping' than any variation in the thickness of the cutting edge), but the direction of the force by which the cutting is effected must be also taken into account. Certain it is, at least in cases where continuous rapid motion is imparted to a tool, or to the work with which it is brought into contact—as, for instance, in the case of a circular saw, the cutting of a rotary planing-machine, wood in the process of being turned, &c.—that the effects produced are quite as much dependent upon the speed as upon the angle and inclination of the cutting edge. No attempt at rigid classification, however, will be made in this and the following chapter, in which it will be impossible for us to do more than to glance briefly at the more ordinary types of cutting-tools used by

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hand,—some insight into their principles being essential to the proper understanding of the action of the various machine-tools which form the main portion of our subject.

It should be observed that simplicity in the form of a tool by no means implies facility in its use. Indeed, the very reverse of this is much nearer the truth, and within certain limits it may be said that the more simple the tool, the greater is the skill required to use it properly. An extreme instance of this will be found in the *scriber*, which is so simple in its form as doubtfully to rank among cutting-tools. It consists merely of a straight pointed piece of steel of circular section, and it is used by workmen for marking on metal, just as a pencil is used for marking on paper. The working part of it being merely a point, it has, when used alone, no tendency to move in one direction more than in another: the 'guide principle,' as it has been termed, being entirely absent. A straight, or curved line, can therefore only be described with it, if the workman is sufficiently skilful to guide it perfectly correctly with his hand, which in mechanical work is out of the question. A scriber is in consequence invariably used in conjunction with a guiding edge of the required form—the difficulty of using it alone being for all practical purposes insuperable.

Neglecting metal tools for the present, we will confine our attentions to those used for wood. Foremost among them is the *axe* (Fig. 13), the general form of which seems to have undergone but little change since the date of flint implements, to some of which the axe-head—more especially the American pattern (Fig. 14)—bears no inconsiderable resemblance. This pattern, which is less cumbrous than the ordinary English axe, has come considerably into use in this country. Both of these are sharpened by being ground equally on each side of the cutting edge.

When it is necessary to produce a comparatively flat surface with an axe—as, for instance, in squaring logs of

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timber—a modified form, known as the *side-axe*, is used, of which the edge is ground on one side only. The flat, or unground side then forms a guiding surface, which enables successive cuts to be made with an amount of precision unattainable with an ordinary axe.

Still greater accuracy can be obtained with the *adze* (Fig. 15), though this is in great measure due to the manner in

FIG. 13.—Axe (⅛).

FIG. 14.—American Axe-head (⅛).

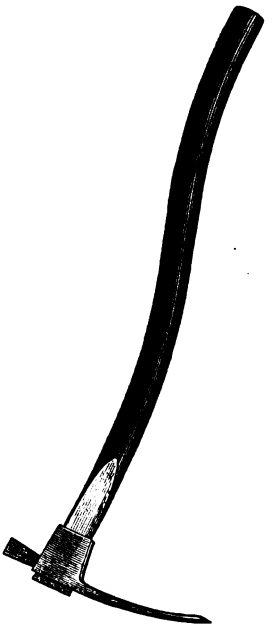

FIG. 15.—Adze (⅛).

which it is held. Standing upon his work, and planting his blows with wonderful effect upon the timber beneath his feet, a good workman wields his adze with such certainty, that he can split the sole of his slipper without fear of

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grazing the skin of his foot. An equally good tool for small work is the *hand-adze* (Fig. 16). In this the handle is attached by an iron strap, in a manner quite as effective as the usual plan of driving it upwards through an eye, and it can be liberated by a single blow from a hammer. Although made in Sheffield for exportation, this tool has never come into use in this country, though it might do so with advantage. Indeed, in the use of most of the varieties of axe, we must confess inferiority to our trans-Atlantic and other neighbours, who export instead of importing their timber.

FIG. 16.—Hand-Adze (⅛).

For the magnitude of their effects in comparison to the amount of energy expended, the various forms of axe and adze certainly stand unrivalled amongst wood-tools, combining as they do the cleaving power of a wedge with the force of impact of a hammer. Their edges, however—more especially those of ordinary axes—have so small an amount of guiding surface, that a very high degree of skill on the part of the operator is necessary, in order to make the cut in the desired position and direction. It is of course advantageous for the edges of these tools to have as small an amount of thickness as is consistent with sufficient strength to resist the treatment to which they are subjected; the angles of their cross sections therefore vary from about 25° to 40°, according to circumstances, those of the side-axe and adze generally approaching the smaller, and that of the common axe the larger, of these angles.

Figs. 17 and 18 show respectively a cast-steel *firmer chisel*, and a steel-faced *socket chisel*, which differ from one another chiefly in the provision for the attachment of their handles. Like the side-axe and the adze, chisels of this kind have 'single bevelled' edges, being ground on one side

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only. By keeping the unground side pressed closely against the work, the tendency of the edges to run into the material can be completely resisted ; the even pressure with which a chisel is driven where thus used for paring, being especially favourable to this application of the 'guide principle.' In this manner small surfaces can be made almost as flat as with a plane ; but it should be observed that this can only be done as long as the original flatness of the unground face of the chisel is not interfered with.

In the *mortice chisel* (Fig. 19), which may be either firmer

FIG. 17.
Firmer Chisel (⅛).

FIG. 18.
Socket Chisel (½).

FIG. 19.
Mortice Chisel (½).

or socket-handled, the guiding power of the unground face is also taken advantage of in cutting the vertical sides of mortices. Chisels of this kind have considerable extra thickness given to the blade, to enable them to stand the rough usage which they are liable to meet with. The width of their edges and that of carpenters' chisels generally is

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rarely less than $\frac{1}{8}$th of an inch, or more than 2 inches. All of these are sharpened by grinding them on one side only, as already stated (but which cannot be too strongly impressed upon a beginner), at an angle of from 20° to 30°, according to the hardness of the material to be operated upon, a small facet at a somewhat greater angle (ordinarily exceeding the former by about 10°) being afterwards formed upon an oil-stone, for the purpose of giving a smooth and clean cutting edge.

The *carpenter's gouge* (Fig. 20) is also either socket or firmer-handled, and it is ground and set in the same manner, and at much the same angles as the foregoing, but the bevel being generally on the convex side, its cut is much less easily guided.

FIG. 20. Carpenter's Gouge ($\frac{1}{2}$).

Except for the removal of moderately thin or narrow shavings, the pressure of one or both hands is insufficient for working a gouge or chisel. It is then propelled by successive blows upon the end of its handle, for which purpose a *mallet* (Fig. 21) is much to be preferred to a hammer. The latter, whilst more destructive to the handle of the tool, is less effective in driving it into the work.

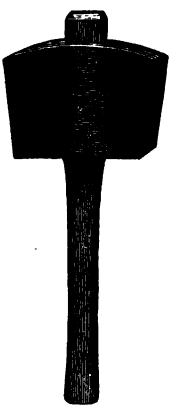

FIG. 21.—Mallet ($\frac{1}{8}$).

From the carpenter's paring chisel, an easy step leads us to the *draw-knife* (Fig. 22); for although they differ greatly in form, the depth of their cut is controlled in a precisely similar manner. This consists, as previously mentioned, in keeping the flat side of the blade towards the surface of the work, its tendency to run into it being either wholly or partially resisted by raising or depressing it. From the

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position of the handles, it is obvious that a draw-knife could not be applied to a surface whose width exceeded the length of the cutter; but, in fact, its use is much more restricted by the amount of power which is necessary to remove, even from soft wood, a shaving which is wide as well as thick. Neither this, nor any of the preceding tools, the depth of whose cut is dependent upon the inclination of the cutter, are competent to remove very thin or uniform shavings.

With the *spokeshave* (Fig. 23) this is to some extent possible, for this tool will be found on examination to differ from the preceding in principle, much more than in form. Fig. 24 represents a section through the centre of a spokeshave, from which it will be seen that the piece of (beech or other) wood which carries the cutter is not in this case merely a convenient form of handle; it is an integral part of the tool itself. Running along the whole length of the blade, it forms a guide which renders it impossible for the cutting edge to penetrate the work beyond a certain fixed depth. By regulating this depth we ought to be able to remove with this instrument perfectly uniform shavings of any required degree of thinness. But in practice, a spokeshave of this sort is by no means as efficient a tool as it would appear to be, and it is never employed where much

FIG. 22.—Draw-Knife ($\frac{1}{8}$).

FIG. 23.—Wooden Spokeshave ($\frac{1}{8}$).

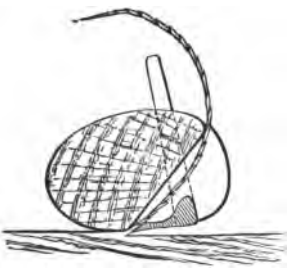

FIG. 24.—Section of Spokeshave.

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accuracy is required. The effect of use is to enlarge the *mouth* (*i.e.* the space between the wooden guide and the cutting edge), more especially towards the centre, where it gets most work. Grinding the cutter further increases this evil, and the cutter itself—of which the upturned ends are rather obstacles to sharpening—is liable to have its edge much thickened by the process, though this may to some extent be prevented by forming a groove in its upper surface (see section of blade in Fig. 24).

FIG. 25.—Spokeshave with Double Iron.

FIG. 26.—Section of Double-Iron Spokeshave.

In all of these respects the iron-handled spokeshaves of the American patterns, of which several are now obtainable in this country, are a decided improvement. The mouth no longer becomes enlarged nor its straightness impaired by use, and the cutter—reduced to a simple piece of flat steel, which may be released by giving less than half a turn to the set screw which holds it—can be sharpened as easily as an ordinary chisel.

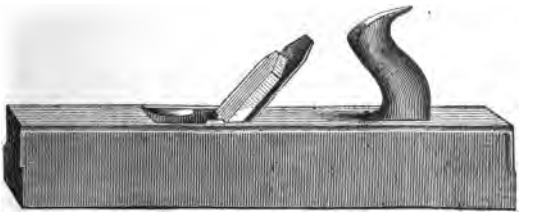

FIG. 27.—Jack Plane.

The action of a spokeshave of this kind is sometimes further improved in the manner shown in Fig. 25, by providing it with a double blade or 'double iron.' An explana-

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tion of the reason of this improvement will be found below, in the description of single and double-iron planes, in connection with which the section of the improved spokeshave (Fig. 26), may advantageously be compared with that of the old pattern (Fig. 24).

As regards their outward forms the ordinary *Jack Plane* (Fig. 27) and the *Smoothing Plane* (Fig. 28) are too well known to need description, but the requirements which have given rise to these forms deserve a little consideration.

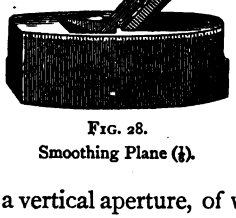

FIG. 28.
Smoothing Plane (½).

In the first place, with reference to the *stock*, which is generally made of beech wood, and which carries the cutter or *plane-iron*, as it is called. Through this stock there is a vertical aperture, of which the lower portion serves the same purpose as the wooden guide in the case of the spokeshave, and forms, with the cutting edge, the *mouth* of the plane. This, as we have seen, would be sufficient to regulate the penetration of the cutter, but it would not prevent it from following all the inequalities of the surface to which it is applied. Now the object of planing a surface is to render it flat, by removing its inequalities, and for this it is necessary that the cutter should act upon the projecting portions only. This end is simply and effectually attained by giving considerable length to the stock, which causes a plane, in operating upon a rough piece of wood, to remove successive shavings from the more prominent parts, until they are all brought down to the level of the deepest depression in its surface. When this has been done, a continuous shaving can be taken from the whole length of the piece, and the surface (if narrow) is approximately flat. How nearly it approximates to perfect flatness depends upon the skill of the workman, who knows, among other things, that he must try to plane it slightly 'hollow,' rather than 'round,' since,

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if he uses a plane sufficiently long in the stock, it is impossible for him to give any great amount of concavity to a surface of moderate length. For this reason jack planes, with which the first roughing-out of a surface is done, have as much length given to them as is possible without making them cumbrous—*i.e.* from about 14 to 17 inches. *Trying* (or true-ing) *planes*, whose office is to correct the inequalities left by the former, are from 22 to 24 inches, or—if intended for making long joints, in which case they are called *jointers*—28 to 30 inches; whereas smoothing planes, which have merely to give the finishing cut to the already flattened surface, are only about 8 inches long.

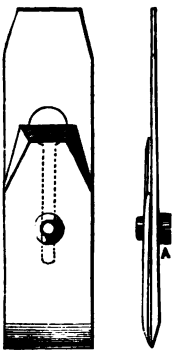

FIG. 29.
Double Plane Iron (½).

The *plane-iron*, of which the lower part of one face only is made of steel, was formerly a simple chisel-like blade from $\frac{5}{8}$ths to $\frac{7}{8}$ths of an inch narrower than the sole of the plane; but this has been greatly improved of late years by attaching to its upper surface a second inverted blade of the same width as the first. Together they form the *double-iron* shown in Fig. 29, which for surface planes has almost entirely superseded the old single-iron. The *top-iron*, though it takes no part in the cutting of a shaving (and consequently when once sharp it never again requires sharpening), enables the bottom-iron to make a much cleaner cut, more especially when the grain of the wood is unfavourable. Fig. 30, which shows in section the mouths of a single and of a double-iron plane, will explain the reason of this. It must be borne in mind that the tendency of a cut to run with the grain of the wood in advance of the cutting edge, which is sufficiently obvious in removing a thick shaving, exists also, though to a less degree, in the case of a thin one. This results, when the direction of the grain is unfavourable, in

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the continual tearing up of the fibres of the wood in front of the plane iron, to an extent which depends upon the thickness of the shaving and the frequency with which it is broken; for the more often this is done the less leverage can it exert in tearing up the succeeding fibres. Now an ordinary plane has a *pitch* of about 45°, *i.e.* the *bed* upon which the iron rests is at that inclination, and this angle is insufficient to break a soft-wood shaving if moderately thin; so that although the shaving is smooth, the surface of the work is liable to be left rough. As a remedy it might be suggested to increase the pitch; but this, though it would certainly improve the breaking-power of the iron, would tend to make it scrape

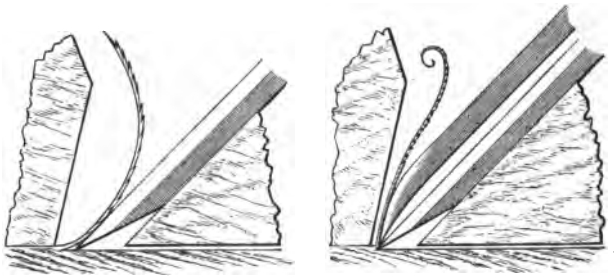

FIG. 30.—Sections of Mouths of Single and Double-Iron Planes.

instead of cutting. So recourse is had to the double-iron, in which the duty of the top-iron is simply to break the shaving as soon as possible after it has been cut. By means of the screw (A, Fig. 29) which keeps them in contact, it can be set at any required distance from the edge of the bottom-iron, but the more closely it is set the more often is the shaving broken, and the more power has the workman to expend in the operation. It is therefore set very close to the edge for finishing cuts, when the shavings are very thin, and farther from it when they are thicker, the maximum being about $\frac{1}{16}$th of an inch.

The ordinary angle of the bed upon which the plane-iron

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reposes was stated above to be about 45° from the sole. This is known as *common-pitch*, and is adopted for all surface or *bench-planes* for soft wood. But for the harder kinds of timber, in the working of which a nearer approach to a scraping action is admissible, an increased pitch is adopted with advantage. The angle of that known as *York-pitch*, which is preferred for bench-planes for mahogany, wainscot oak, and other hard and stringy wood, is 50°, that of *middle-pitch*, 55°, and that of *half-pitch* 60°, these two being used for moulding planes for soft and hard wood respectively. The angle of the bevel produced by grinding the bottom-iron of a plane is about 25°, the small facet formed upon the oilstone having—as in the case of a chisel—a further inclination of some 10°, so that the actual angle of the cutting edge is about 35°.

Some hints as to the maintenance of the edges of plane-irons and hand-tools generally will be found at the end of present chapter, so that we will only mention here that the iron is removed for the often-recurring operation of sharpening, and is afterwards replaced, and 'set' as follows :—The wedge which holds the plane-iron having been released, —in the case of a smoothing-plane by one or two blows from a hammer or mallet on the hinder end of the stock, in that of a jack or other long plane by similar blows upon its upper surface near the opposite extremity,—the double-iron can be removed from the aperture in the stock. The upper iron should then be separated from the lower by loosening the screw (A, Fig. 29) and passing its head through the enlarged end of the slot in the lower iron. As already stated, the top-iron, when once brought to its proper shape, requires no further treatment whatsoever, its sharp edge being only necessary to insure its perfect contact with the face of the bottom-iron, by which, when in use, it is completely protected. Laying this aside therefore, the operator confines his attention to the bottom-iron, the under or bevilled face of which he grinds and sets as required, leaving the upper

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face altogether untouched, or at most only rubbing it very slightly on the oilstone in such a way as not to impair its flatness.

This done, the top-iron is replaced, screwed-up securely, and the double-iron is returned to the stock. The wedge which holds it being driven up lightly in the first instance, the plane is then 'set' by a succession of taps with a light hammer upon the end of the iron, or upon the stock, according as the projection of the edge below the sole is insufficient or excessive. By running the eye along the sole from front to back, the amount of this projection can be easily seen. It must of course vary with the thickness of the shaving which it is intended to remove, the wedge being driven up when the desired set has been obtained.

In course of time the mouth of a plane gets considerably enlarged, by which its power of breaking the shavings is diminished and its action interfered with. To remedy this, the part of the sole immediately in front of the cutter is occasionally made of iron. Cabinet-makers, who carry the use of the plane to the greatest perfection, use stocks which are wholly or in great part made of iron or brass. Some of these have a single iron inverted, instead of a double one, more especially if (like *mitre-planes*) they are intended for planing across the grain of the wood, when no special precautions for breaking the shavings are required. The mouth of a plane of this kind is shown in section in Fig. 31, the stock being entirely of brass, with the exception of a piece of wood upon which the iron is bedded. The angle of the bed is in this case only 21°, but the reversed position of the iron, which is ground at an angle of 20° and set at about 30°, makes it equivalent to a pitch of about 50°. The

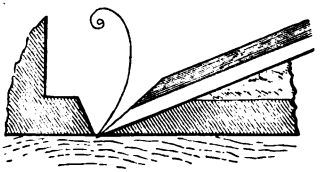

FIG. 31.
Section of Mouth of Brass Plane.

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extreme fineness of the mouth, coupled with this increase of pitch, compensates for the absence of a break-iron in planing hard and cross-grained wood, even in the direction of its fibres, with a tool of this kind. In this, as well as in the preceding sections, the portion of the blade which is left white approximately indicates the portion of the 'iron' which is made of steel.

Planes with cast-iron or steel stocks, in which the thickness of the shaving can be exactly regulated, either by an adjusting lever or a thumbscrew, and which dispense with the hammer also in the removal of the iron for sharpening, &c., are now imported from the United States. One of these, with the thumb-screw adjustment, is shown in Fig. 32.

FIG. 32.
American Smooth-Plane.

The various forms of plane for special purposes are too numerous even for mention here. Amongst them are—*moulding planes* (Fig. 33), for 'running' various kinds of beads, flutings, ogee and other mouldings, which have their soles made of hard wood and formed to

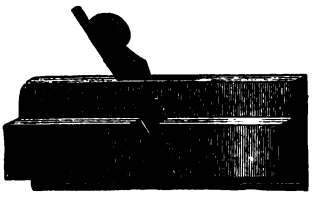

FIG. 33.—Moulding-Plane ($\frac{1}{8}$).

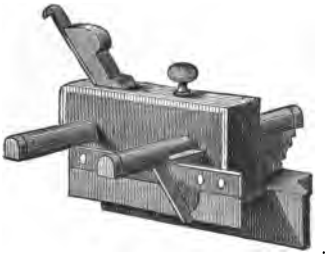

FIG. 34.—Plough ($\frac{1}{8}$).

the converse of the mouldings they produce; *rebate-planes*, in which the lower part of the plane-iron is increased to the full width of the sole, and is frequently set obliquely; and many others, of which the irons are single, and the

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performance more or less defective. But since the introduction of wood-moulding machinery, their occupation has in great measure gone. A very useful but complicated form of plane is the *plough* shown in Fig. 34, which is capable of cutting grooves of varying widths, depths, and distances from the edge of the work ; the first being regulated by the width of the 'iron,' the second by a stop worked with the thumb-screw which appears at the top, and the third by the adjustable 'fence,' seen projecting below it in the engraving.

In concluding these few remarks about planes it should be mentioned that although a sharp and fine-mouthed plane imparts to a wooden surface a flatness and a smoothness

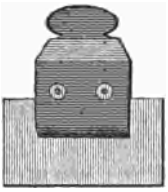

FIG. 35.—Wood Scraper (½).

FIG. 36.—Burred edge of Scraper.

which can scarcely be improved upon, yet the final finish is often given by other means.

Scraping,—the system upon which, as we shall presently find, the perfection of highly finished metal work is so largely dependent,—is applicable only to the harder kinds of timber. For these, however, the *Wood Scraper* (Fig. 35) forms a very efficient tool, capable of giving a true and clean surface to hard wood even when 'cross-grained.' It consists merely of a small steel plate, clipped, for convenience, by an easily removable handle. The scraping edge is either sharpened on an oilstone exactly to a right angle, and used in that condition, or a slight 'burr' is thrown up by burnishing the edge with the stem of a large brad-awl, or any similar piece of steel harder than the scraper itself. A rough

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idea of the effect of this may be gathered from the diagram (Fig. 36), in which the edge of the scraper, much enlarged, is supposed to be seen in section.

A piece of window-glass is sometimes used as a scraper, but there are many objections to it for this purpose.

It is when ground, sifted, and glued upon paper or cloth that glass becomes a valuable assistant to the worker in wood. With *glass-paper* or *glass-cloth* the final smoothing of the more finished kinds of wood-work is almost always performed, the method of applying it to flat surfaces generally being to fold it over a piece of cork with a flat rectangular face; and similar means applicable to curved surfaces will readily suggest themselves. To the turner and the polisher too glass-paper is almost indispensable. The following are the sizes generally used in London :—No. oo or 'Flour' (which is the finest); No. o; No. 1; No. 1½; Fine 2 (or F 2); Middle 2 (or M 2); Strong 2 (or S 2); No. 2½; and No. 3 (which is the coarsest).

But we must pass on to what are perhaps the most indispensable of all the tools of the wood-worker, viz. *Saws*, of which some familiar examples will be found in Figs. 37, 38, and 39. The size and shape of the blade, its thickness, and the form and pitch of the teeth, are their chief distinguishing characteristics. We will briefly examine their differences in these respects, and the causes of those differences; which will be seen, by referring to p. 52, where they are given in the tabular form adopted many years ago by the late Mr. Charles Holtzapffel, to range between much wider limits than is usual amongst hand tools. The table contains only a small number of saws, such as are most likely to come under notice, but of course many other varieties might have been included between the two extremes—the 10-foot pit-saw on the one hand, and the fret-saw, scarcely thicker than a horse-hair, on the other.

The *Hand-saw* (Fig. 37) may be taken as the type of all the 'taper' saws handled at one end, which make their cut

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during the forward or downward stroke. Being intended for straight cuts only, considerable width is given to the blade, so that it may have but little tendency to deviate from the straight line. At the same time it is very desirable that the blade should be equally able to resist the thrust at all parts of the cut, and this is sufficiently secured by making it 'taper.' The thickness of a taper saw blade is also regu-

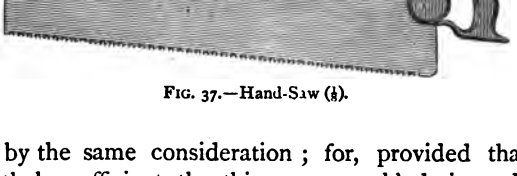

FIG. 37.—Hand-Saw (⅛).

lated by the same consideration; for, provided that the strength be sufficient, the thinner a saw blade is made, the less material does it waste in making a cut, and the smaller is the amount of power which must be expended in the operation. Thus *compass-saws* (Fig. 38), and others which have narrow blades, so as to enable them to saw round curves of moderate radius, have much greater thickness

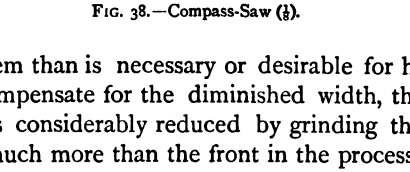

FIG. 38.—Compass-Saw (⅛).

given to them than is necessary or desirable for hand-saws, so as to compensate for the diminished width, though this thickness is considerably reduced by grinding the back of the blade much more than the front in the process of manufacture.

Back-saws (Fig. 39), which are strengthened by a piece of iron or brass folded over the back of the blade, are able to have the thickness very much reduced, but as the depth of

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the cut is limited to the width of the blade, it is necessary to make saws of this kind parallel instead of tapered.

By reversing the teeth of a saw, so as to make it cut during the backward instead of the forward stroke, the thickness and width for enabling it to resist flexure is rendered

FIG. 39.—Back Saw (⅛).

unnecessary; for, whereas a thrust has a tendency to bend the blade, a pull only tends to straighten it. But with a few exceptions—such, for instance, as the saws with thin curved blades, which have now superseded the cumbrous double-toothed pruning-saws of former days—this principle is only applied in this country when the blade is stretched

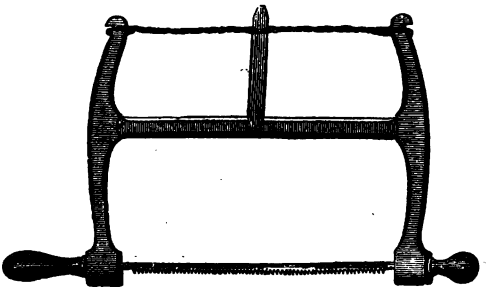

FIG. 40.—Bow-Saw (⅛).

in some kind of frame. In all these *bow-saws* (such as Fig. 40), the thrust is taken by the frame, and the pull or tension only by the blade, which can therefore be reduced, both in width and thickness, to any required extent. Saws of this kind are therefore used for sawing out all curves of small radius, for cutting metal, ivory, and other substances of which

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it is an object to waste as little as possible, and also in the endless-band sawing machines. Pit-saws and the smaller sizes of cross-cutting saws also frequently have frames, and on the continent of Europe and elsewhere frame-saws are advantageously used for many purposes to which they are not applied in England.

Three types of *Saw-Teeth*, to which most of those formerly in use in this country may be referred, are shown in

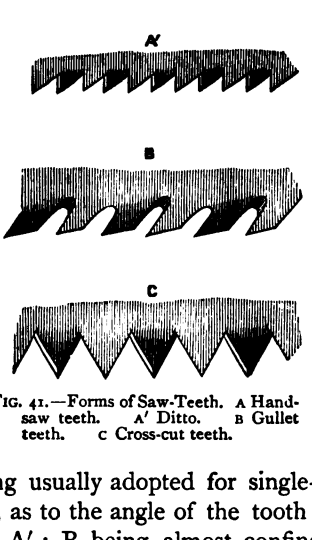

FIG. 41.—Forms of Saw-Teeth. A Hand-saw teeth. A' Ditto. B Gullet teeth. C Cross-cut teeth.

Fig. 41 ; A being usually adopted for single-handled saws, varied, however, as to the angle of the tooth so as more or less to resemble A' ; B being almost confined to pit-saws working in the direction of the grain of the wood, and C to large cross-cut saws used for cutting across the grain.

It is evident that a saw-tooth which is well adapted for producing a clean cut in one of these directions would be ill adapted for doing so in the other,—at least in the case of fir and other soft timber. For in sawing with the grain the

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readiness with which the short section of fibres sliced off by each tooth parts from the fibres by its side (owing to their very slight lateral cohesion) assists in the operation, and a fairly clean cut results. But in cross-cutting special provision is required for cleanly dividing the fibres at each side of the cut, after which the removal of the intervening fragments can be accomplished readily by cleavage rather than by cutting. The rationale of the above forms of tooth is thus clear. The sharp chisel-like edges of the gullet tooth (B) are well adapted for slicing the fibres of the wood transversely ; the cross-cut teeth (C), consisting of a series of lancet-like points acting alternately at each side of the cut, divide the fibres

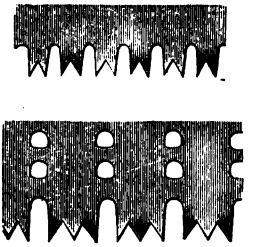

FIG. 42.— M-Teeth.

cleanly, but leave the cut portions to crumble out as best they can ; and the hand-saw teeth (A) are a sort of compromise between the two, so that they can be used either for 'ripping' in the direction of the grain or for cutting across it, though not with the best possible results.

The M-*teeth* (Fig. 42) provide both for the clean separation of the fibres and the removal of the fragments, in whichever direction the saw may be moving. They are thus an improvement upon ordinary cross-cutting teeth, and are coming much into use, in spite of the drawback which attaches to them of requiring special files for sharpening them. In the saw shown in the lower half of the figure perforations are introduced with a view to saving labour in filing.

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Taper Saws.

	Form of tooth [1]	Length of blade	Width Max.	Width Min.	No. of teeth per inch	Thickness: By Birmingham Wire Gauge	Thickness: By Whitworth's Standard Gauge
With a handle at each end		ft.	ins.	ins.			
Cross-cut saw [2] .	C	4—10	6 to 12	3 to 7	8 in 5 ins.	12 to 15	110—70
Pit-saw . . .	B	4—10	9 to 12	3½ to 5	4 in 3 ,,	12 to 16	110—65
Pit frame-saw .	B	4—10	7 to 11	3 to 4½	8 in 5 ,,	15 to 18	70—50
With a handle at one end		in.					
Rip-saw . Half rip-saw .	A or A′	28—30	8 to 9	3 to 4	3— 3½	18 or 19	50—40
Hand-saw . .	A or A′	10—26	5 to 7½	2½ to 3	5— 6	18 or 19	50—40
Panel-saw . . Fine panel-saw.	A or A′	10—26	4 to 7½	2½ to 2	7— 12	19 or 20	40—36
Table-saw . .	A or A′	18—26	1⅜ to 2¼	1 to 1½	7— 8	16 to 19	65—40
Compass-saw. .	A′	10—20	1 to 1½	¾ to ¾	7— 9	18 to 19	50—40
Keyhole-saw. .	A′	6—12			9—10	19 or 20	40—36
			PARALLEL SAWS.				
With backs		in.					
Tenon-saw . .	A or A′	12—16	3 —4		10	21 to 23	32—24
Dovetail-saw .	A or A′	6—10	1½—2		14—18	24 to 25	22—20
With frames							
Woodcutters' or billet saw .	A or C	24—36	2 —3½		3— 4	19 to 22	40—28
Turning, or sweep-saw . .	A′	6—22	1/10— ⅝		10—20	19 to 24	40—22
Smith's frame saw	A′	6—18	¼— ⅞		10—14	20 to 24	36—22
Fret-saw . .	A′	3—14	3/16—1/60		30—90	1/10 to 9/100 in.	20— 5

[1] See Fig. 41. The forms there given are general examples only, and not accurate representations of either the sizes or the angles of the teeth.

[2] Fish-bellied, having its greatest width at the centre of the blade. Teeth somewhat resembling B, and various others are also used.

According as hand-saw teeth are formed to the angle of A or A′ (Fig. 41), the amount of pressure required to force them up to their work is increased or diminished. This 'feeding' pressure, as it may be called, depends largely upon the position of the handle with regard to the general line of the teeth, so that a wide taper saw, with the handle high

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above this line, such as the *Hand Saw* (Fig. 37), will require teeth resembling A, whereas the *Compass Saw* (Fig. 38), in which the handle is below rather than above the line, will admit of teeth of the more greedy form A′. The hardness of the wood upon which a saw is intended to be used also influences the angle of its teeth. But however suitable the form of the teeth may be in the first instance, the efficiency of a saw can only be maintained by *sharpening* and *setting* it from time to time. Of these two operations the object of the first is to renew the cutting edges which have become blunted, at the same time bringing each exactly into line with its fellows and spacing them equally throughout ; that of the second to provide the means of obtaining sufficient extra width in the saw-cut (or *saw-kerf*) to enable the blade to pass through it freely and without 'binding.'

The only method of sharpening with which we need concern ourselves is that of *saw filing*, as a grindstone clearly cannot be used for the purpose, and saw sharpening, or 'saw-gumming' machines, by which the teeth of large saws are very successfully treated with artificial emery wheels, are not as yet applied to the angular teeth of hand saws, to which we will confine our attention.

For these, triangular, or *three-square files*, are invariably employed, on which account the angle between the face of one tooth and the back of the next is in almost all cases the same as those of an equilateral triangle, or 60°. Outline sketches of 'taper' and 'parallel' three-square files, and also of the 'gulleting' and 'topping' files used for gullet teeth, will be found in Fig. 68. In order to apply them conveniently, the saw—having been previously removed from its frame, if it be a bow-saw—is fixed with its teeth upwards, in a vice, or a sawing-horse, the latter, however, being seldom or never used except for pit-saws. But whatever the form of holder, the object to be attained is to support the saw blade between two jaws of wood or other soft material, at as small a distance from its teeth as can be done

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without interfering with the free use of the file. This, before being applied to the individual teeth, should be removed from its handle, and passed lengthwise a few times along the points of the whole of them—those at the ends, which come in for a smaller amount of wear, frequently requiring to be lowered or 'topped' more than the others, in order to bring them to the same level. By this treatment a small horizontal facet will be left on the point of each tooth. In filing each of them separately—which is the next step—its newly formed point must be brought exactly to the centre of this facet, which can be readily done by removing a larger proportion from the face or from the back of the tooth, as may be required. The file, however, should not be inserted into each space consecutively. When filing fine teeth it is advisable, and when filing coarse ones it is necessary, to do them alternately from opposite sides, and this is most easily effected by omitting every alternate space in the first instance, then releasing the saw from the vice, turning it end for end, and filing those previously omitted. The file is seldom held at right angles to the saw blade, but is inclined to it both horizontally and vertically to a greater or less degree, according as it is intended to make the cutting end of each tooth approach more nearly to the chisel-like edge, which (as already pointed out) is effective only for sawing in the direction of the grain, or to the lancet-like points of a cross-cut saw. For general purposes the vertical inclination is apt to be about one half of the horizontal, as the diagram (Fig. 43) shows. Bearing in mind that (in filing angular teeth) the handle of the file should never be raised above its point—

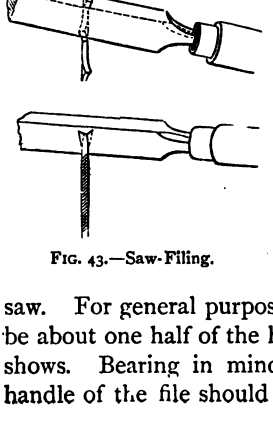

FIG. 43.—Saw-Filing.

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in other words, that the stroke should be upwards instead of downwards, and that the greater the noise the less is the effect produced upon the saw—the reader will have no difficulty in determining for himself which are the spaces which should belong to the first series and which to the second.

In the above diagram it will be observed that the teeth are not in line with the saw blade, but that their points are bent alternately to the right and left, so that their cut will exceed the thickness of the blade to an extent depending upon the amount of this bending, or *set*, as it is called. Without the clearance due to this 'setting,' saws could not be used in soft wood, which requires it much more than hard wood. Whether little or much, the amount of the set should be perfectly even throughout, which can best be judged of by observing the back view, where the points of the teeth appear somewhat in the manner represented in the wood-cut (Fig. 44).

There are various ways in which the set can be given to the teeth. The saw-maker lays the toothed edge of the blade upon a small curved stake or anvil, and with one or two blows from a light, narrow-faced hammer he quickly bends each alternate tooth downwards, to an extent depending upon the curvature of the anvil, and the position of the tooth upon it. When half the teeth have been done in this way, the saw is turned end for end, and the other half is similarly treated.

FIG. 44.
Set of Saw-Teeth.

Joiners and others who are users, but not makers, of saws, generally employ some kind of *saw-set* in preference to the saw-setting hammer. In its most simple form a saw-set may be merely a piece of steel plate of a thickness not exceeding the width of the saw-tooth, having in its edge a parallel-sided notch, equal

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in width to the thickness of the blade. For convenience, however, a saw-set is usually provided with a number of notches of varying widths, so as to enable it to be used for saw-blades of different thicknesses. The saw to be operated upon is fixed with its teeth upwards, in the same manner as for filing, and the teeth, separately inserted a short distance into a notch of suitable width, are alternately bent in opposite directions by raising or lowering the handle of the saw-set. To do this equally to all the teeth without any kind of stop or guide is by no means an easy task, and since uniformity of set is of such great importance, some less simple saw-set generally produces more satisfactory results in inexperienced hands. The addition of an adjustable stop to the notched plate is of some assistance, as it prevents the teeth from being bent to different angles ; but those known as *patent saw-sets*, by which the teeth are clipped between the jaws of a pair of pliers of peculiar form, are provided with adjustments which leave nothing to the discretion or the indiscretion of the operator. In others, again, a kind of miniature swage is held up by a spring over a small stake or anvil, upon which the saw-block rests. A single blow from a hammer at the top of the swage completes the set of each tooth, perfect uniformity being insured by adjustments which regulate the inclination of the blade and the distance to which it can extend on to the anvil. These saw-sets, if made more generally applicable to saws of various shapes and sizes than they are in their present form, would probably be found to be more speedy and effectual than any others.

As a test of the uniformity with which the operations of setting and sharpening a saw have been conducted, it has been suggested to place a needle in the angular groove formed by the tops of the teeth (which appears in the section in Fig. 43). On gently raising one end of the saw, the needle should run from end to end without leaving the groove.

Although our mention of the setting of saws has been

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deferred till after the subject of filing them had been dismissed, this order is not that which should be followed in the process of sharpening. If, indeed, so large an amount of topping be required as almost to amount to re-forming the teeth, the course adopted in the original manufacture—in which they are brought to their true form, set, and then sharpened by filing—may be advantageously followed; but in ordinary cases, setting should precede filing. The 'burr' thrown up by the file, which has much to do with the keenness of a newly sharpened saw, is then retained uninjured. In fret-cutting and some other kinds of saws

FIG. 45.—Brad-awl.

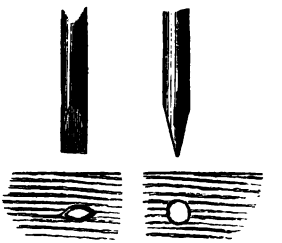

FIG. 46.—Action of Brad-awl.

this burr constitutes their only set; but as the prevalent practice is to file such teeth from one side only, instead of alternately from opposite sides, these saws have the tendency to 'draw,' instead of making a straight cut, which is always the result of giving more set to one side than to the other.

Of the wood-tools generally used for *boring*, the *brad-awl* (Fig. 45) seems to claim precedence, not indeed from the perfection of its performance, but because, being very simple in its form and speedy in its action, it enjoys a sort of monopoly wherever small holes have to be made in soft wood. When properly placed, with its edge across, and not

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in the direction of the fibres, so that it may cut them instead of merely forcing them asunder, a sharp brad-awl—especially if driven with a hammer or mallet instead of being worked by hand—will produce in deal and other loose-fibred woods a fairly clean and circular hole, without much danger of splitting, as Fig. 46 will serve to explain. For boring hard woods, which require a portion of their substance to be removed, brad-awls are not adapted, as they have no means of effecting this.

Recourse is then generally had to the *plain gimlet*, or to the *twist gimlet* (Fig. 47), although in this latter the

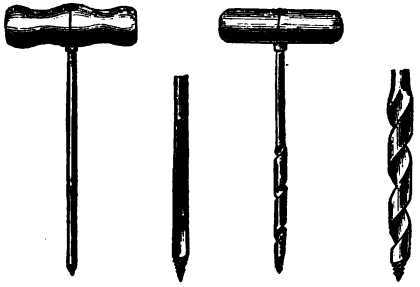

FIG. 47.—Plain and Twist Gimlets

strength is insufficient for boring woods of which the hardness is excessive. The size of gimlets like those shown in the figures does not in general exceed $\frac{3}{8}$ of an inch; others, however, resembling the *screw-auger* (Fig. 50) are as much as $\frac{3}{4}$ of an inch. The pointed screw by which they are made self-feeding has considerable tendency to split any wood that is given to splitting, and the insufficient size of the groove to contain the whole of the material displaced causes a gimlet soon to become choked. This necessitates its frequent withdrawal when boring a deep hole, whereby its naturally slow action is rendered slower. At best, indeed, this tool is far from perfect, the expenditure of both time and power being

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out of all proportion to the effects produced. But it is perhaps to these imperfections that we owe the introduction of pointed wood screws, which are a very great improvement on the old-fashioned ones with blunt ends.

For either of these older forms the *twisted shell gimlet* (Fig. 48) may generally be substituted with advantage, as it is almost free from the foregoing objections. The long tapered end which it gives to any hole which does not pass through the material may, however, be objectionable in some cases.

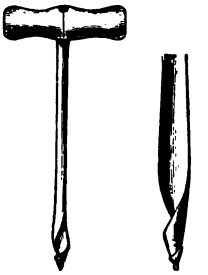

FIG. 48.—Twisted Shell gimlets.

The principal tool for boring holes of which the diameter or the depth is too great for a gimlet, is the *auger*. The *shell-auger* and also the *screw-auger*—which has to a great extent superseded it for boring soft wood—are shown in Figs. 49 and 50. But for hard woods their great strength is likely to enable shell-augers to hold their own, in spite of the advantages which their rivals possess in being self-feeding, capable of being worked with much less power, and not so liable to become choked. The cutting ends of a shell-auger and two kinds of screw-auger are shown enlarged in these figures. For fixing the long cross handle, by which the requisite leverage for working an auger is obtained, the upper end of the stem is either drawn out to a tang of great width but slight thickness, which can be driven through the centre of the handle and clenched; or an eye is formed, through which it can be passed. In the engravings the shell-auger (Fig. 49) is 'tanged,' and the screw-auger (Fig. 50) is 'eyed'; the tang being always placed with its greatest width across the grain of the wood, so as to reduce the risk of splitting it. Occasionally the tang is made square, like that of a brace-bit, which enables one handle to serve for several augers. The diameter of the cutting part of an auger

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generally ranges from $\frac{3}{8}$ of an inch to 2 or $2\frac{1}{2}$ inches. Shell-augers of 3 inches diameter and upwards were formerly used for boring wooden pumps and pipes, but with them they have now ceased to be manufactured. Shell-augers when once started—an operation in which they require the assistance of a gouge or other tool—are kept straight in their course by the guiding power of the hollow parallel 'shell,'

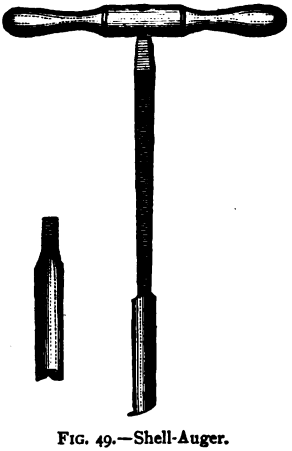

FIG. 49.—Shell-Auger.

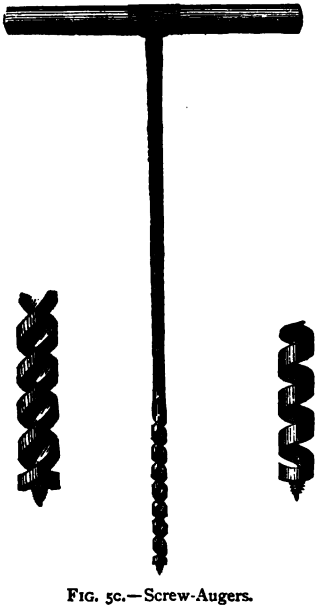

FIG. 50.—Screw-Augers.

which extends for some inches above the cutter. But the friction thus produced consumes so much power, especially in the larger sizes, that it is more advantageous to bore a hole of large diameter in two operations; first making a small hole, truly concentric with that required, and afterwards enlarging it by means of a tool on the same principle as the plug-bit shown in Fig. 56. This, however, does not

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apply to those screw-augers which have two cutting edges, the resistance encountered by one edge being equal to that met with by the other, so that the whole tool is in a state of equilibrium, and little or no guiding is required. We shall revert to this subject in connection with the drill (see Fig. 73).

None of the preceding tools are well adapted for fine

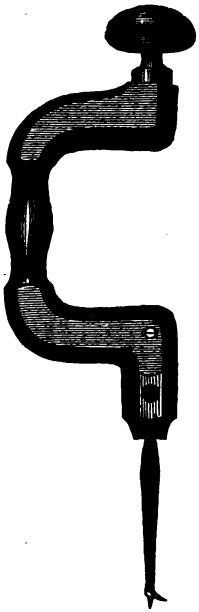

FIG. 51.—Brace and Bit.

FIG. 52.—Details of Jaws.

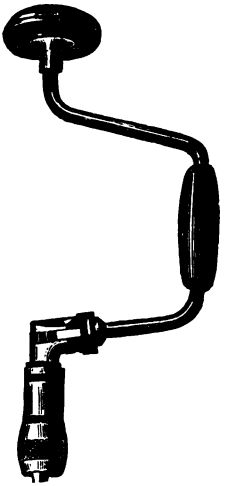

FIG. 53.—American Brace, with Ratchet and self-fitting Jaws.

work, in which it is essential that holes should be perfectly smooth and accurate. For these purposes a *brace* and set of *bits* offer great advantages, not the least of which is the number and variety of borers which can thus be carried in a small space. The English pattern of *brace* (or *stock*) is shown in Fig. 51, and an American brace which contains several

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important improvements upon it, in Fig. 53. In this the jaws are so constructed that they will accommodate themselves to almost any square-shanked bit, independently of its size or the amount of its taper, and they can even be used for holding round shanks. Their principle will be understood from the enlarged section of them given in Fig. 52. The ratchet, which is ingeniously arranged to drive in either direction, as required, the portion of the brace shown in the section, is intended to be used only in places where there is not room for the crank to make a complete revolution.

The set of bits which accompanies an English brace con-

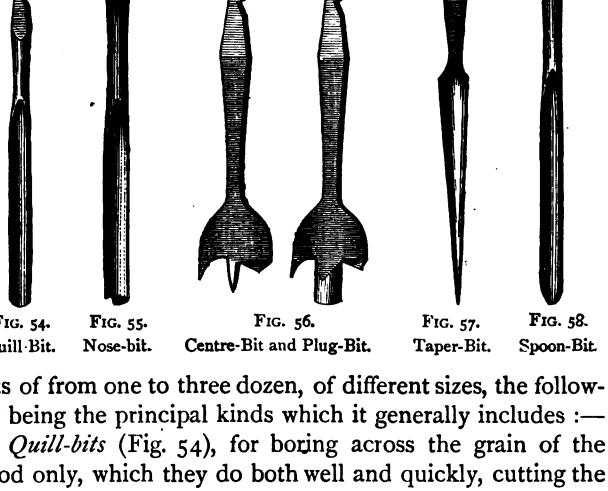

FIG. 54. Quill-Bit. FIG. 55. Nose-bit. FIG. 56. Centre-Bit and Plug-Bit. FIG. 57. Taper-Bit. FIG. 58. Spoon-Bit.

sists of from one to three dozen, of different sizes, the following being the principal kinds which it generally includes :—

Quill-bits (Fig. 54), for boring across the grain of the wood only, which they do both well and quickly, cutting the fibres instead of tearing them apart. These, and almost all other brace-bits, are fed by the pressure of the chest of the workman against the top of the brace.

Nose-bits (Fig. 55), differing only from quill-bits in having at their extremity a transverse cutter, which enables them to

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be used for boring in the direction of the grain. They much resemble shell-augers.

Centre-bits (Fig. 56), for boring holes of small depth (up to about two inches in diameter) at a single operation, or rather by two distinct operations which are carried on simultaneously. A triangular pin or 'centre' carries on one side a knife-edge or 'nicker,' and on the opposite side a 'cutter.' The distance between the centre and the outer face of the nicker is exactly equal to the radius of the hole produced, the width of the cutter being rather less than this. At each revolution the nicker makes a clean circular incision, and from the space inclosed by it the cutter then removes a helical shaving, whose thickness depends upon the pressure applied to it. The efficiency of this tool is much greater when it is used across the grain of the wood than in the direction of it. For boring a large hole concentric with an existing small one a centre-bit is not adapted, unless the central pin be enlarged so as completely to fill the hole which is to be followed. It is then called a *plug-bit*, but it is a tool of special rather than general application.

Besides these, a set of bits generally contains *taper-bits* or *rimers* (of which Fig. 57 shows that used for wood), *countersinks*, for enlarging the entrance of holes to admit the heads of screws of which Fig. 59 shows two kinds, and one or more *screwdrivers*.

Spoon-bits (Fig. 58), used for the same purpose as nose-bits, to which they are superior, are also to be found in the larger sets.

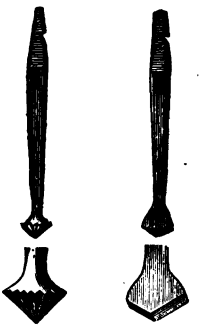

FIG. 59.
Rose Countersink and Metal Countersink.

Three patterns of bits which are of more recent introduction, and are not quite so well known as the foregoing, are given on the next page. All of these are self-feeding, as wood-boring tools should be.

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Screw-bits (Fig. 60); very superior to centre-bits, for which they would more often be substituted if their prime cost were not considerably greater.

Twisted Shell-bits (Fig. 61), similar to the gimlets already figured (Fig. 48).

Expanding Centre-bits (Fig. 62), with which holes can be bored exactly to any required diameter within tolerably wide limits.

With these the examples of wood tools must end. The list has been necessarily a meagre one, but our

FIG. 60.
Screw-Bit.

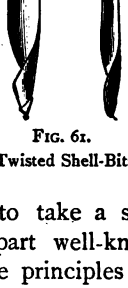

FIG. 61.
Twisted Shell-Bits.

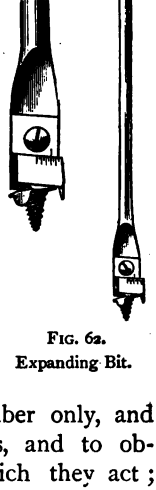

FIG. 62.
Expanding Bit.

endeavour has been to take a small number only, and those for the most part well-known ones, and to observe something of the principles upon which they act; at the same time noticing the direction which improvement in them is now taking, or in which it seems still to be desirable.

But however well suited to their purpose and excellent in quality his tools may be, a handicraftsman cannot turn out thoroughly good work if he neglects or improperly

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carries out the renewal of their cutting edges from time to time. The following notes in connection with hand-tool grinding and setting may, therefore, prove serviceable, and they are especially recommended to the notice of a beginner, who should include these most important operations amongst his earliest lessons.

On attempting, for instance, for the first time to sharpen his plane-iron, he will almost certainly find himself beset with difficulties. Assuming that his grindstone runs perfectly true and that its face is neither 'hollow' nor 'round,' the selection and maintenance of the proper angle at which to hold the tool will be found to be far from an easy matter, any variation either in its height or in the angle at which it is applied to the stone causing a fresh facet to be formed upon it. The tendency is thus to grind the bevelled face convex, and this must be carefully resisted by obliging it constantly to keep the same position. When this has been successfully accomplished, the face will be slightly and uniformly concave, to an extent which will vary with the diameter of the grindstone. Attention must also be paid to forming the edge of the tool square to its sides, by keeping every part of it evenly pressed against the stone; which is most easily done by placing the fingers of the left hand on its upper surface, as nearly as possible over the centre of the bevel which is being ground upon its lower one. The amount of pressure which must be applied will of course vary much with the width of the tool, and it will also be influenced by the direction in which the grindstone is revolving, more being required when its upper portion moves away from the operator, and less when it runs towards him. In the latter case, however, the edge of the tool is more liable to catch, and thereby to damage both itself and the face of the stone; whilst in the former a wire edge somewhat difficult of removal is thrown up directly the grinding has been continued sufficiently long to obliterate the small facet previously left by the oilstone. An obvious remedy for this is to discon-

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tinue the operation before the grindstone quite reaches the cutting edge, whenever the removal of notches or other inequalities does not necessitate its continuance. In the case, therefore, of such tools as, after being ground, are to be finished upon an oilstone, the direction in which the stone revolves may be said to be immaterial. For others—such as turning tools for metal—of which the cutting edges are often wholly produced upon the grindstone, it is preferable that it should be driven towards the operator.

Since the difficulty of grinding edge-tools properly is enormously increased if the grindstone be allowed to lose its true cylindrical form, or if its face be worn unequally, care should always be taken to guard against this by giving a slow lateral motion to a tool whilst it is being ground. Neglect of this in the case of those which are flat but of small width—such as chisels, &c.—soon results in the formation of a hollow at the part of the stone at which the work is chiefly performed, which causes it to give a curved instead of a straight edge to those—such as plane-irons—of which the width is greater. These indeed cannot possibly be ground correctly, if the centre of the grindstone face be worn hollow to any considerable extent.

In grinding carpenters' gouges and other tools of which the bevelled edge is curved, this traversing motion is even more necessary, for if held constantly in the same position they very rapidly 'score' the face of the stone and make the commencement of a groove, which is not easily got rid of. Where much use exists for gouges or any kind of tool of which the convex surface requires to be frequently ground, it is preferable to devote a separate stone to them and to allow its face to become grooved. When their edges, although curved in one direction, are straight and at right angles to their length, the required curvature can be easily given by constantly turning the wrist of the right hand, in which the tool is grasped, backwards and forwards through a larger or smaller arc of a circle according to the amount

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of the curvature. Gouges, however, are ground occasionally on their concave instead of on their convex sides, and for these as well as for various moulding and other tools, grindstones, if used at all, must have corresponding projections turned upon their faces. But in such cases—as also in sharpening the generality of boring tools, &c.—the grindstone is frequently abandoned in favour of the file; or recourse is had to an iron or copper *lap* charged with emery powder. Or—which is now the more usual practice in the grinding of all difficult shapes—emery is used in the form of the consolidated *emery wheels*, to which we shall revert in connection with machine tools.

In order to prevent the temper of edge-tools from being injured by the heat generated in grinding them, and also to maintain the face of the stone in the best condition for 'cutting' the steel, water is supplied to it, either by allowing a small quantity to drip upon the face or by letting the stone dip into a trough of water. Which of these two methods is preferable depends upon the nature of the stone and the speed at which it revolves. A practical disadvantage of the water-trough is, that it begets the temptation to leave the stone standing in the water whilst at rest, of which the result is to soften it, and to cause it to wear unequally. If at any time from this or from other causes a grindstone betrays any eccentricity, the process of turning up, though not perhaps an agreeable one, should at once be performed. If deferred, the evil will always be found to increase, until at last it becomes intolerable, and 'hacking' (*i.e.* dressing off the more prominent parts with a hack hammer) must be resorted to. It is indeed the best method of correcting large grindstones, whether much or little has to be removed from their face; but for small ones it is only necessary in extreme cases, in which it is preliminary to, but not a substitute for, turning. For this latter purpose the stone should be dry and should be driven slowly, the tool, which is generally a worn-out three-square file, being held with its point slightly

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inclined downwards upon a rest fixed as closely as possible to the face of the grindstone. The triangular section of the tool enables a fresh edge to be brought into play by merely turning it over as soon as its upper edge ceases to cut.

Of the various kinds of grit-stone which are used for grinding, that known as *Bilston* (from the place of that name in Staffordshire, where it is extensively quarried) is by far the best suited for sharpening the generality of hand-tools, having a fine and quick-cutting grain without too great hardness. Others obtained from Northumberland, Yorkshire, Derbyshire, &c., are much used in the manufacture of cutlery and hardware, but for the most part (although they vary considerably) they are of coarser grain, and consequently require to be driven at a much higher speed. For grinding the concave facets of moulding tools, and for some special purposes for which great smoothness of grain is required, thin discs of a good but costly kind of *Bohemian* stone are employed. Some years ago Mr. Frederick Ransome turned his attention to the manufacture of grindstones by the artificial process with which his name is connected, and these were reported to have certain advantages over the natural stone, amongst others being that of a reduction in the first cost.

The *hones* and *oilstones* available for setting the edges of cutting-tools form a much larger class than the stones used for grinding them. But although these are obtained from many parts of the globe, they for the most part occur either within very narrow limits or in comparatively small pieces—this, indeed, being more especially true of some of the best varieties. On this account they are rarely mounted and used in the same manner as grindstones, although if they were obtainable in equal abundance this would probably be the general practice. As it is, the workman is obliged to content himself with a rectangular piece from five to nine inches long, upon the surface of which he produces a small facet at the extreme edge of his plane-iron or other

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tool, by rubbing it briskly backwards and forwards as nearly as possible along its entire length. To prevent an oilstone from getting broken—an accident to which some kinds are very liable—and to protect its oily surface from dust, it should always be mounted in a piece of hard wood and be provided with a cover.

In theory the operation of setting a cutting-tool—like that of grinding it—is simplicity itself; being merely the formation of two flat facets inclined to one another at a certain angle, their intersection forming the cutting edge; and indeed in tools which are ground with a single bevel it is only necessary to produce one of these facets, the flat unground side taking the place of the second. But in practice there is great difficulty in continuing the operation just so long as to obtain the complete intersection of the facets at all parts of the edge, without anywhere throwing up the wiry film already mentioned, which is formed upon the oilstone as well as upon the grindstone. Its presence, however, is quite incompatible with the possession of a keen and durable edge, and its removal must therefore be effected whenever it occurs; which may be done, though not very readily, by drawing the edge across a piece of soft wood, or over the thumb nail. In any tool ground with a single bevel, slight treatment of the unground side also upon the oilstone will be found to assist in removing the wire edge, but in doing this care must be taken to keep it flat on the stone and in no case to form a facet on its edge, which, as already pointed out, in almost all cases is a certain method of destroying its efficiency. Chisels and other straight-edged tools, when being set, are best held in such a manner that the direction of the motion of the hands is nearly but not quite at right angles to the line of the cutting edges, as may be seen in the operation of setting a plane-iron, which is represented in the engraving, Fig. 63. But in the case of carpenters' gouges—which we have before taken as the type of edge-tools with this kind of curvature—it is preferable to

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set the edge by moving it in the direction of its length. For this purpose the right hand, in which the tool is grasped, is held considerably to one side of the stone, every portion of the edge being then brought into contact with its surface at each forward or backward stroke by means of a similar wrist motion to that given in grinding it. Concave facets, which of course cannot be produced upon a flat stone, are formed by means of *oil slips*, which are merely thin pieces

FIG. 63.—Setting a Plane-iron.

of oilstone of which the edges are rounded with the required curvature.

The chief points which require to be attended to in connection with an oilstone are: 1st, the maintenance of its flatness, which it always loses with use, owing to greater wear taking place at the centre than at the ends. It must, therefore, from time to time be surfaced by grinding it down on the side of a grindstone, or with fine sand and

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water upon a flat stone or metal surface. Secondly, its cutting power must be preserved ; the coagulation of the oil upon its surface frequently either wholly destroying or greatly interfering with the abrading action of the particles of silica, to which both gritstones and oilstones owe their property of acting upon hardened steel. For this the best remedy is to rub the face occasionally with a lump of moistened pumice-stone. In every well-regulated work-shop, both grindstone and oilstone should be constantly kept in a state of efficiency, and be ready for use at any moment.

The following are the principal kinds of hone and oil-stone from which a workman is likely to be able to make his selection—the order in which they are placed being approximately that of their abrading power ; those at the top of the list being the 'fastest cutting,' a quality which is generally accompanied by a want of fineness in the edge produced.

1. Washita Oilstone.—A very compact white sandstone, of rather recent introduction, almost resembling Carrara marble in appearance. Although it does not greatly differ in price from Turkey stone, its much greater uniformity and slightly more rapid cutting property cause it to be in more favour with carpenters and others, with whom coarse-ness of edge is not an objection.

2. Turkey Oilstone.—When of good quality no better substance can be employed for setting tools for which great fineness of edge is not required, since it cuts the hardest steel with avidity, even when but little pressure is applied. At the same time it is of a close grain, and is not easily scratched. Unfortunately it is very variable in quality, as it is also in colour ; the latter, which is called 'white,' 'grey,' or 'black,' being generally a veined mixture of different shades of bluish and brownish greys. Its cost is about three times that of the stone next mentioned.

3. Charnley Forest Stone.—Found near Mount Sorrel, in

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Leicestershire. This is the best of our native oilstones, and has long been a favourite with carpenters and others, that from the Whittle Hill Quarries, which is of a grey colour, dappled or streaked with red, being considered to be the best. Till lately this has hardly been obtainable—the only representative of Charnley Forest stone being a rather inferior one with a decided green tint. Both of them, however, give a very fairly fine edge, but do not cut quite so rapidly or with as slight pressure as Turkey.

4. Canada Oilstone.—A very fine porous sandstone of a greyish white colour, which has been recently introduced. Being much less compact than any of the preceding stones, it is much more rapidly worn away. Its first cost is, however, rather less than that of Charnley Forest.

5. Grecian Hone.—Under this name a slaty stone is imported, which is of a greenish colour, and, although said to be superior to Welsh oilstone, does not greatly differ from it in appearance.

6. Welsh Oilstone.—A hardish stone of a green colour and slaty texture, inferior to the Charnley Forest for joiners' use. In price it is about the same, as also is the Grecian hone, No. 5.

7. Arkansas Oilstone.—Cuts slowly, but is very superior to all those above mentioned for giving a fine edge to surgical instruments, &c. Although extremely costly—its price being about four times that of Turkey stone—it is extensively used for such purposes. In colour it resembles Washita oilstone, but it is of very much finer grain and wears away very slowly.

8. German Hone.—Thin slabs of a very soft yellow stone, cemented upon a rather harder but similar material of a slate-blue colour, are imported and sold under this name. The extreme softness of the former renders it almost useless for such edge-tools as we have been considering, although it is well adapted for setting razors.

Besides the above, some other kinds of stone, used with

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water instead of with oil, may be employed for sharpening edge-tools. Such is the Water of Ayr Stone, of which the chief use, however, is for smoothing marble, copper, &c.—purposes which are outside our subject.

When greater smoothness of edge than can be given with any of the above hones is desired, it may be finished, after setting, by giving it a few strokes under a light pressure on a leather strop; though for wood tools in general this is not required. Passing it a few times over the palm of the hand,

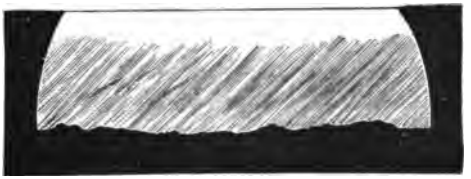

FIG. 64.—Edge of a sharp Razor, × 1000.

which is not an uncommon practice amongst workmen, has doubtless a similar effect.

Absolute smoothness, however, appears to be quite unattainable—at least with a thin edge. The approximation to it in the case of a razor, carefully set and stropped, is shown in Fig. 64, which represents a portion of the edge of a new 'Army' razor, as seen under a powerful microscope.

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CHAPTER III.

ON HAND-TOOLS FOR CUTTING METAL.

ONE distinguishing feature of cutting-tools for iron and the harder metals is the much greater thickness which is given to their edges, their cutting angles being generally from 50° to 90°, and in some cases as much as 120° ; whereas those of wood-tools, as we have seen, rarely exceed the smallest of these angles, and are for the most part much below it. Chisels, for instance, when they are intended to be used for chipping wrought iron, have their edges ground to an angle of 50°, and, when cast iron has to be operated upon, to an angle of 60° ; although thin edges, if they could be made to stand (which they cannot), would undoubtedly require a smaller amount of power to be expended in making a cut.

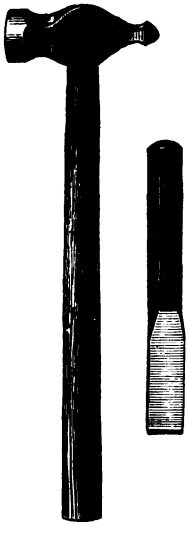

FIG. 65.—Hammer and Chipping Chisel (¼).

In working the harder metals by hand, the *chipping chisel* driven by a succession of blows from a *hand hammer* (ordinary forms of both of which are shown in Fig. 65) constitutes a more important tool than its representative among wood-tools ; the hard and stubborn nature of these materials entirely forbidding the use of anything corresponding to the axe, with which the first roughing-out of timber can be effected. On the other hand, it might be thought that, by careful forging and casting, the desired forms could be pro-

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duced without any subsequent treatment, and where moderate correctness only is required this is so to a great extent. And the desirability of dispensing entirely with costly finishing processes in all such cases is becoming increasingly recognised. But wherever great accuracy of form is essential—as in the working parts of good machinery—these cannot be dispensed with, as the oxidised surface of an iron or steel forging, or the hard gritty skin of a casting would be unsuitable even if it were true. And the necessity often arises, even in these days of machine tools, for treating some portion of such surfaces in the old way—by hand-chipping and filing.

In the case of small surfaces this is generally commenced by cutting away the entire skin, to the depth of about $\frac{1}{32}$ of an inch, with a chipping chisel of about the size and width of edge represented above (*i.e.* from 6 to 8 inches long, and from $\frac{3}{4}$ to 1 inch wide); but in the treatment of large surfaces the operation is much facilitated by first making a series of parallel groves with a *cross-cut chisel*, of which Fig. 66 is an example, though its edge may even be much narrower with advantage. Its width regulates that of the grooves, and their distance apart should not exceed the width of the chipping chisel with which the intermediate portions of the material are to be removed. When small V-shaped grooves have to be cut with a chisel, its shape is modified accordingly; the single bevel with which it is ground then presenting the form of a 'lozenge,' or 'diamond'; on this account it has received the name of a *Diamond-point.* The weight of the hand hammer ordinarily used with a chipping chisel varies from one to two pounds—its form also varying according to the fancy of the workman.

FIG. 66.—Cross-cut Chisel (¼).

The depth to which the edge of a chisel penetrates is

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regulated by the strength of the blow and the angle at which it is held. Since, in the choice and maintenance of the latter, the angles of the double-bevelled edge render little or no assistance—in other words, since it possesses so very small an amount of guiding power—it is not to be wondered at that proficiency in the art of using a chisel can only be acquired by practice. Among other points a beginner should remember: First, that the edge of a chisel may be slightly rounded with advantage in the direction of its length, so that its corners may not have a tendency to score the work or be so easily broken off; secondly, that in operating upon any surface of which the width exceeds that of the chisel, the line of advance should for the same reason be kept constantly convex; and thirdly, that if he desires to avoid collisions between his hammer and his knuckles, he will do well to keep its face and the end of his chisel free from grease.

For large castings, or for portions of them from which a considerable quantity of metal has to be removed, *Flogging chisels*, which are held in hazel rods or 'withes' by one man and struck with a sledge hammer by another, are substituted for the ordinary hand chipping chisels. But in many cases the skin of a casting is removed by grinding, or by 'pickling' it with dilute sulphuric acid, which dissolves some of the iron and thereby releases the particles of sand; either of which methods renders unnecessary the tedious and expensive process of chipping.

We next come to the consideration of *Files*, which form a very extensive class, upon which, more than upon any other, the users of such tools as belong to the present chapter are dependent. Although in technical language they are not comprehended amongst cutting tools, any more than saws are included amongst the edge-tools used for wood, we cannot see that any good purpose would be served by excluding either the one or the other from the positions which they here occupy. The use of files is

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by no means confined to the working of metals, some kinds —as we shall see—being but little adapted for the treatment of hard materials, yet this constitutes by far the larger proportion of their duty. On this account we have hitherto omitted all mention of them, preferring to group together the whole of those which can be noticed within the narrow limits at our disposal.

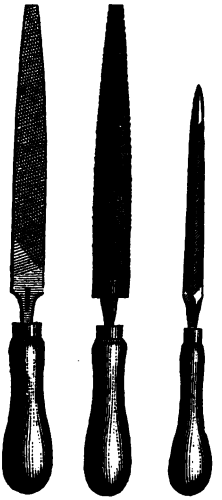

FIG. 67.
Files and Rasps (½).

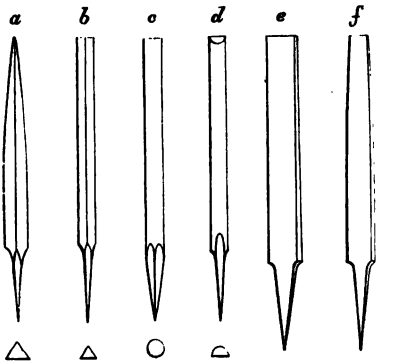

FIG. 68.—Saw-Files. *a* and *b*. Three-square Files. *c*. Gulletting File. *d*. Frame-saw or Pit-saw File. *e* and *f*. Mill-saw or Topping Files.

For the complete description of almost every individual file, five different properties must be stated:—First, its length; secondly, its contour; thirdly, the form of its cross section; fourthly, the kind of 'cut' by which its teeth are formed; and lastly, its degree of fineness. The examples represented in Fig. 67 will explain this; the first of them being a 9-inch, taper, flat, bastard, double-cut file; the second a 9-inch, taper, half-round, smooth rasp; and the

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third a 6-inch, taper, three-square, second single-cut saw-file. With these characteristics we will deal seriatim.

The *length* of a file is measured in inches from the shoulder to the extremity, the tang or point for driving into its handle not being included.

The contour is described by the terms *parallel* (or *blunt*), and *taper* (or *pointed*), which explain themselves. But 'parallel' includes all files of which the width is tolerably uniform throughout, although the thickness may be considerably greater near the centre than at the ends. Indeed very few files have their section really equal throughout their length. Files are sometimes said to be more or less *bellied* according as they are much or only slightly tapered. In the latter case they may also be described as *blunt-pointed.* Examples of both taper and parallel files will be found in Fig. 68, which gives the outline of those generally used for sharpening saws.

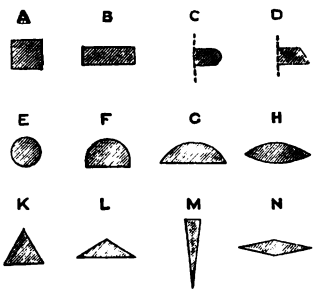

FIG. 69.—Sections of Files.

In Fig. 69 types of most of the *file sections* in common use are given. They are known by the following names :—

A. *Square files*, which are made both taper and parallel. They frequently have one *safe* side ; *i.e.* one side left smooth.

B. *Flat files*, amongst which a large proportion of the files used for mechanical work must be included, although many of them have special names by which their variations in width, thickness, and outline are distinguished. Such are :—*Hand files*, which are nearly parallel as to their width, but whose thickness is far from being uniform throughout. *Taper flat files* vary to a still greater extent in thickness, and also have their sides 'bellied.' *Parallel hand files* approach

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more nearly than hand files to uniformity of thickness and width, and *equalling files* attain to it in point of thickness, and are generally also parallel in width, and thinner than most of the preceding ones. *Pillar files* and *Cotter files* are of rectangular section, but narrower than hand files. *Mill-saw* or *Topping files*, both taper and parallel, are shown at *e* and *f* in Fig. 68. One or both of their edges are frequently rounded as in the half-section C, Fig. 69. Some hand, equalling, and other files have their edges similarly rounded, and some have bevelled edges, as in the half-section D in the same figure.

E. *Round files*, when small and taper, are known as *rat-tail files*. Under the name of *Gulletting files* (*c*, Fig. 68) parallel round files are used for deepening the 'gullets' of the saw-teeth of that name.

F. *Frame-saw* or *Pit-saw files* (*d*, Fig. 68) are parallel (or sometimes taper) files of this section, which can be used for both 'gulletting' and 'topping.'

G. *Half-round files* are almost always taper. Those of the section F have more right to the name, but they are not included except as 'high-back half-round.' Most of the half-round files made in Sheffield are nearly of the proportions given in the section (G); but those made in Lancashire are of three different 'heights'; the thicker and the thinner sections being known as *high-back* and *flat-back* respectively.

H. *Cross* or *crossing-files*, sometimes called *double half-round*. They are made both taper and parallel.

K. *Three-square files*, shown both taper and parallel in Fig. 68. They are very much used both for sharpening saws and for general purposes.

L. *Cant files*, generally parallel, and cut on all three sides.

M. *Knife-edge* or *Knife files*, either taper or parallel.

N. *Feather-edge files*, almost always parallel.

Many of the small files used by clock and watch makers, although the sections resemble those above given, are known

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amongst them by special names, derived for the most part from the particular use to which they are chiefly applied. Thus the crossing file (H, Fig. 68) in all probability owes its appellation to the convenience of its section for filing out the cross arms of clock wheels. Neither this nor the 'cant,' 'knife,' or 'feather-edge' files are often to be found in the workshop of the engineer.

Rubbers are large and coarse files, made of an inferior quality of steel, which are sold by weight. They are generally of the form and section given in Fig. 70, and are used for rough manufacturing purposes, but not for the higher kinds of work.

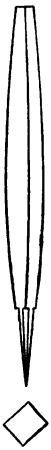

FIG. 70. Rubber.

FIG. 71. Riffler.

Bent files, called *Rifflers*, are made of various degrees of curvature. One of them is represented in outline in Fig. 71. They are the only kind of file which can be brought to bear upon concave surfaces which have any considerable curvature in more than one direction, and they are therefore of occasional use in the workshop, especially among brass finishers, who use them for filing up concave mouldings in brass castings.

With regard to the various kinds of *cut* by which file teeth are produced, we must mention that English files are divided into two distinct classes—*Sheffield files* and *Lancashire files* (Sheffield and Warrington being the places where they are chiefly made), and that these differ from each other in several particulars. Of these the most important formerly was the superiority of those made in Lancashire in respect both of form and durability, but, as far at least as the larger kinds are concerned, this no longer holds good to a sufficient extent to compensate for

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their higher price, although the small files used in clock-making, &c., are still exclusively Lancashire. To one point of difference between them attention has already been called in connection with the 'half-round' section (G, Fig. 69); another is the fact of the 'cut' of Lancashire files, being only of the first kind given on the following page, so that our description must be understood to apply only to those sold as 'Sheffield.'

In Fig. 72 are represented the three principal kinds of *cut* by which files are divided into *double-cut* files (which are always meant when 'files' are spoken of without any particular cut being specified), *Single-cut* files, or *Floats*, and *Rasps*. Besides these there is also another, which differs from the first only in the obliquity of its two series of cuts, (one of them being almost square across the file): it is known as the *New cut*, and is said to have special merits for filing wrought iron. But the first of them is by far the most largely employed, almost all the files used for metal, as well as cabinet-makers' files, and many others, being double-cut. Saw-files, however, are an exception, all varieties of them being frequently, though by no means invariably, single-cut; these when in use being considered by many persons to 'cut sweeter' than those which are double-cut. To these the term 'float' is not applied. Floats are extensively used for preparing brass for burnishing, and rasps chiefly for wood, bone, and other comparatively soft materials.

In addition to the kinds of cut, the engraving, Fig. 72, shows also many of the degrees of fineness in which files are made, together with the names by which they are distinguished. The teeth are represented of the actual sizes which they would be in files 12 inches long, those of smaller files being finer, and those of larger ones somewhat coarser. The complete series is given in the case of the double-cut only, both floats and rasps being also made of about six different degrees.

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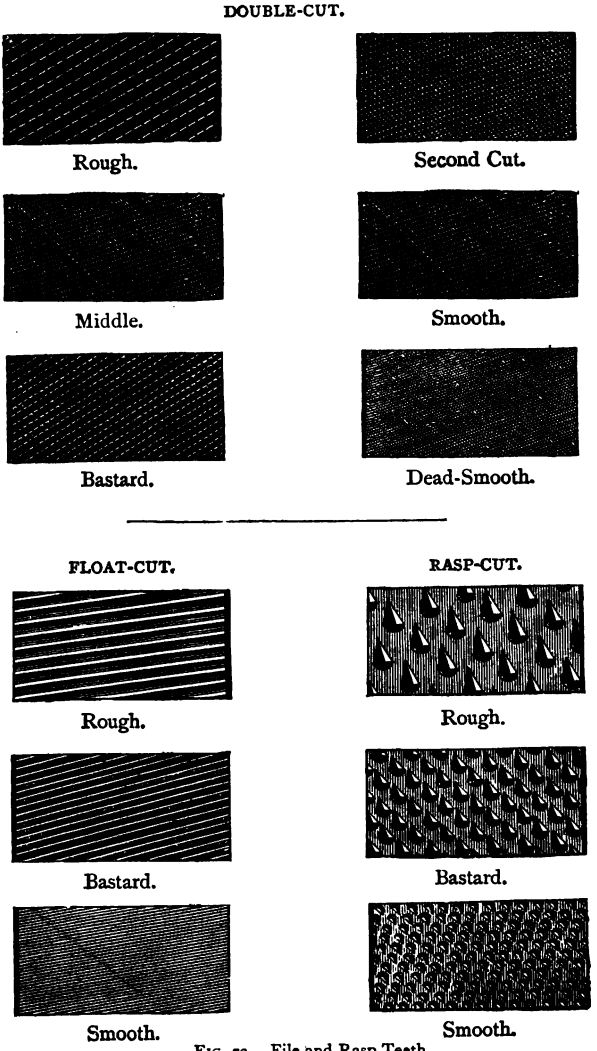

FIG. 72. File and Rasp Teeth.

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As far as the double-cut is concerned, the engraving represents with tolerable truth the teeth of Lancashire as well as of Sheffield files, but among the former the finest are known as *superfine*, and not as 'dead-smooth.' The number and the accuracy of the teeth in some of these is certainly wonderful. Mr. Holtzapffel mentions having himself found that one of the smallest and finest Lancashire files contained nearly 300 cuts per inch of its length; yet these are produced entirely by hand—machine-cutting, although it has been carried out with some success on the Continent of Europe, having hitherto made but little headway in this country. The operation is of such interest, as illustrating the very high degree of perfection which may result from skilful manipulation, that we cannot refrain from giving a slight outline of the process, which is conducted as follows:—The soft cast-steel *blank* is placed on an anvil with the tang towards the operator, and is there held by means of a foot-strap; a suitable piece of lead or pewter being interposed whenever its section requires a V-shaped or other special support, or when the under side has been previously cut. Commencing at the point, the file cutter then makes a series of cuts with a chisel of which the width rather exceeds the width of the cuts, striking it with a hammer which is strictly proportioned as to weight to the amount of burr to be thrown up at each cut, or, in other words, to the degree of coarseness of the teeth. In order to place the chisel correctly he slides its edge a little way along the greased surface of the blank, till it comes into contact with the burr of the preceding tooth. The height of this burr, and the greater or less inclination given to the chisel, thus determine the space by which each succeeding tooth is in advance of the previous one. Double-cut files have two series of cuts inclined in opposite directions to the axis of the file, the edges of the teeth produced by the first series being very slightly smoothed over before the second series is commenced. For rasps the straight-edged chisel is replaced by a pointed

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punch, and in their case the evenness of the teeth depends solely upon the skill with which the file-cutter hops the punch into the right positions. In whatever pattern he may choose to arrange the teeth, his object should always be to place as few of them as possible exactly behind each other.

After being cut, files are straightened and hardened, during which process they are coated with a mixture which protects their teeth from the direct action of the fire.

Drills, which are, perhaps, the next more largely used of workshop appliances, trench so closely upon the province of 'machine-tools,' that it is difficult to say how far they may be properly included in this chapter. For a drill without some mechanical arrangement by which sufficient speed or power for driving it can be obtained, is as useless as an auger without a handle, or a plane-iron without a stock. In default of a better distinction, we shall, therefore, only notice here some of the steel drills themselves, and the *portable braces*, &c., in which they are sometimes used.

Most drills for metal have two similar cutting edges, a characteristic by which they may be broadly distinguished from those used for wood. This makes them, from a mechanical point of view, much more perfect instruments, as will be seen from the diagram, Fig. 73, which gives sectional plans of a spoon-bit (*a*), a centre-bit (*b*), and a drill (*c*); the hole bored by each being represented by the circle. Supposing the rotary motion to be produced in each case by two equal and opposite forces, it will be noticed that in *a* one only of these forces is employed in cutting; the other being expended in merely pressing the back of the shell against the side of the hole, giving rise to the great friction and heating to which tools of this class

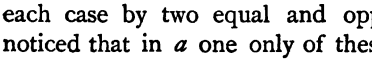

FIG. 73.

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are subject. In *b* a portion of this opposite force is utilised in driving the 'nicker,' the remainder producing a side strain upon the central pin. In *c*, however, both of them are wholly consumed in cutting, and, the tool being in perfect equilibrium, it is possible for it to maintain the straightness of its course and the circularity of the hole without such support as is afforded by the shell in the one case and by the central pin in the other. But this distinction does not obtain universally, in each class there being some exceptions; such as the double spiral screw-bit previously mentioned (Fig. 60), and the Swiss drill (*b*) in the engraving below, which are examples of double-edged wood-borers and single-acting metal-drills respectively.

In Fig. 74 the cutting portions of various kinds of drill are represented. Of these *a* is the ordinary watchmaker's

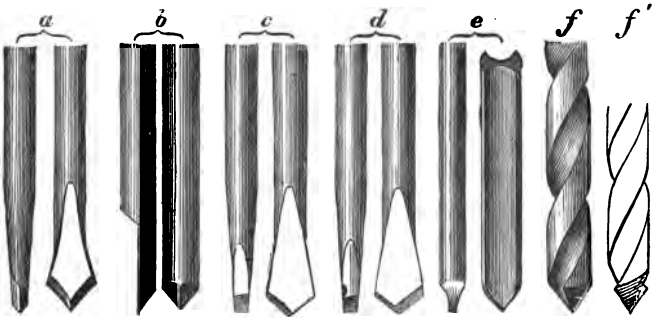

FIG. 74.—Drills.

drill, which, although it scrapes rather than cuts, is more efficient than might be expected, when its size is small and its revolution rapid. For a drill of this kind indeed, which is to be driven alternately backwards and forwards—which these generally are—double-bevelled edges are better adapted than those with a single-bevel, since the latter, although they might cut more quickly when revolving in one direction, would do nothing when moving in the other. One great

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disadvantage in this form of point is that the diameter of the hole produced by it is altered every time the drill is sharpened ; which, however, can be obviated by making its sides parallel for a short distance above the cutting edges. From doing this another result—and a most important one —also follows, viz. the sides are enabled to assist in the guidance of the drill, which is thus rendered much less liable to change its direction during its advance, in consequence of any slight alteration in the direction of the pressure applied to it, or any other cause. With a drill of the form *b*, which also cuts when revolving in either direction, it is almost impossible to drill a hole otherwise than straight ; and however frequently it may be sharpened its original diameter is maintained.

The rest of the drills in the engraving are adapted for cutting in one direction only. Those which resemble *c* have but little inclination to enter the material which is being drilled, since the angle of their cutting edge is by no means acute, and its front face is either at right angles to the surface upon which it is operating, or is slightly tilted forwards. This, combined with the bluntness of the point—which is an evil inseparable from this form of drill—necessitates, in the case of the harder metals at least, the application of considerable *feeding* pressure, so that a drill of this kind may be kept up to its work ; its action is then not otherwise than rapid, and is perfectly analogous to that of the metal cutting tools used in the lathe. The great heat evolved, however, forbids any but a very moderate rapidity being given to it. By simply forming a groove in the front face of each of the cutting edges, as shown in that marked *d* in the figure, any desired degree of acuteness can be given, the strength of edge required for the particular material under treatment being the only limit to the extent to which this may be done. To this plan, however, the much greater amount of grinding necessary whenever the edges of the drill require to be renewed is an objection.

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Two kinds of drill, in which the principle of making them self-guiding by providing them with parallel edges is fully carried out, are shown in *e* and *f*. The former is known as the *fluted* drill, and the latter is the *twist* drill. Their difference, as far as their cutting edges are concerned, corresponds with that just pointed out with reference to the drills *c* and *d*. In *e* the front face of each edge (which is formed by one side of the groove or fluting) is perpendicular to the surface of the work, so that the depth of its cut is dependent upon the feeding pressure. But in *f*, by the simple and beautiful expedient of carrying the groove spirally round the stem, any moderate inclination can be given to this face, and, however much the extremity may be ground away, its angle always remains invariable. In sharpening either of these drills, it is necessary to grind the extremity in such a manner that the lower face of each cutting edge shall form a portion of an independent spiral, instead of allowing both of them to become part of one and the same conical surface. In *f'* the spiral face is shown much exaggerated, but its pitch may be slightly varied according to the nature of the material to be drilled and the extent to which the strength of the edge may be reduced in operating upon it. But however strong an edge may be required, the point must never be absolutely conical, of which the effect would be similar to that of grinding the drill *c* without any bevel (*i.e.* with the cutting angle equal to the following angle of its edge), in which case no available pressure would suffice to feed it. Consequently the small angle which this face forms with the surface of the work—which corresponds with that called by Mr. Babbage the 'angle of relief' in the case of metal turning and planing tools—is absolutely essential to the working of a

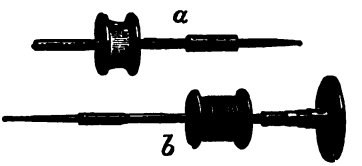

FIG. 75.—Bow-Drill Stocks (½).

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drill ; and with every increase in this angle a correspondingly diminished pressure is capable of giving an equal amount of feed ; in other words, the more greedy the drill becomes. The superiority of twist-drills has of late years been increasingly recognised, and they are now extensively used for drilling iron and even for steel, as well as for softer materials. But for working them to full advantage the regular and accurately directed pressure obtainable with a lathe or drilling-machine is necessary. (See Chapter VII.)

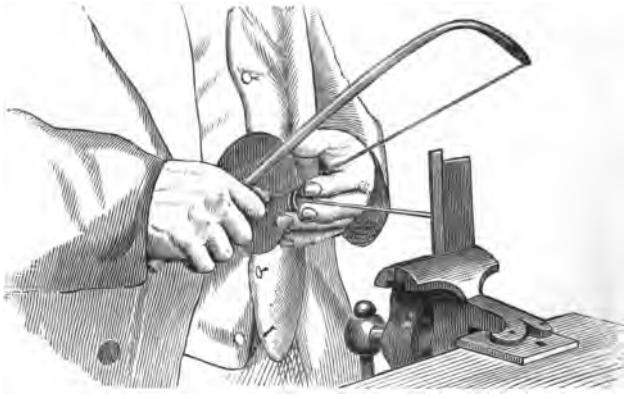

FIG. 76.—Drilling with Bow-Drill.

In drilling holes of very small diameter, we have seen that the pointed form of tool employed by watchmakers and others requires rapid rotation alternately in opposite directions, with but little feeding pressure. These conditions are well satisfied by the ordinary bow-drill (*a*, Fig. 75), the method of using which will be evident from Fig. 76. The drill is either fixed in a stock, as shown above, or is itself of sufficient length to carry a wooden sheave or barrel, round which, when in use, the string of the *drill-bow* takes a single turn, the pointed end of its stem resting meanwhile in a shallow centre hole in a sheet-iron *breast-plate*, strapped

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round the chest of the workman ; or, if the work cannot conveniently be so fixed that the drill may be held horizontally (or nearly so), the breast-plate may be held in the left hand, by which, when the drill is small, ample pressure can be applied. In *b*, Fig. 75, is another form of bow-drill stock, for which no loose breast-plate is required. A coarse screw-thread cut upon the surface of its barrel saves the gut, of which the bow string is generally made, from chafing at its point of crossing. The bows in question, when small, are almost invariably made of whalebone, larger ones being generally made of cane, but occasionally of steel.

The *Archimedean drill-stock* (Fig. 77) is an invention which dispenses with the necessity for either breast-plate or

FIG. 77.—Archimedean Drill-Stock (½).

bow, the motion of the right hand being, by means of the spirally grooved stem, converted into rotation, which in its constant change of direction resembles that obtained from the drill bow. But it is by no means an equally economical application of power, and—probably on that account—it has not at present done much towards supplanting the bow-drill amongst those who have much use for such instruments. The many-threaded spiral shown in the engraving is produced by twisting a piece of pinion wire—but the grooves of these drill-stocks are frequently much fewer in number and of larger size.

The *bevel-wheel drill-stock* or *brace* (Fig. 78) may in many cases be conveniently used for drilling holes which are of

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larger size than those for which the foregoing stocks are adapted; but which, at the same time, are not so large as to require a greater amount of feeding power than is obtainable by letting the flattened head bear against the chest of the workman. Its construction is sufficiently clear from the engraving; but the proportion between the bevel wheels in some of these stocks is such as to give a greater, and in

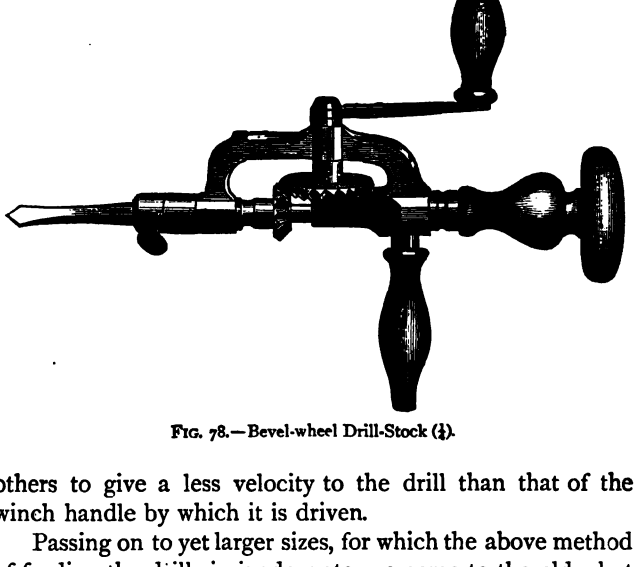

FIG. 78.—Bevel-wheel Drill-Stock (¼).

others to give a less velocity to the drill than that of the winch handle by which it is driven.

Passing on to yet larger sizes, for which the above method of feeding the drills is inadequate, we come to the old—but simple and efficient—*smith's brace*, which is represented in position for use in Fig. 79. It will be observed that it requires to be constantly associated with a *cramp*, one end of which must be provided with a feeding screw; unless, indeed, the brace itself contain one, in which case the cramp may consist simply of a stout bar bent to the requisite form.

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(In the engraving both the cramp and the brace have feeding screws, but this is superfluous.) For drilling small articles, the cramp must in turn be supported in a *tail-* or *bench-vice* (as in the figure), or the place of this may be taken by a *pillar*, either temporarily or permanently fixed to the bench, on the surface of which the work is then placed, an adjustable horizontal arm carried by the pillar receiving the thrust from the upper end of the brace. Another method of feeding the drill, which has long been employed in blacksmiths' shops, is to arrange a lever in such a manner that a heavy weight at one of its extremities may constantly press downwards upon the brace placed below it near the other; but this, although it is superior to the cramp or pillar arrangement, since it gives a continuous and self-acting feed, can hardly be classed amongst portable forms of drilling apparatus.

FIG. 79.—Smith's Brace (⅛).

When portability is a main consideration—more especially as in such cases the space required for working an ordinary brace is frequently not available—some kind of *ratchet-brace* is almost always substituted for it. This admirable contrivance is represented in Fig. 80 almost in its original form; and although much ingenuity has been expended in devising modifications of it, its general principle and appearance have remained unaltered. The stock, in the lower part of which the drill is fixed, contains its own feeding-screw, of which a portion appears in the engraving below the elongated hexagonal nut. By this nut, which forms the entire upper

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portion of the stock, the feeding-screw is wholly concealed when it is screwed home. The hand-lever on the right in the figure is capable of revolving round the body of the stock, but as the stock has a ratchet-wheel upon it and the lever carries a click, the effect of imparting to it a backward and forward motion is to cause an intermittent revolution of the stock and the drill which is fixed in it. At the same time any desired feeding pressure can be obtained by simply arresting the upper portion of the stock during the forward movement of the lever. A short length of the

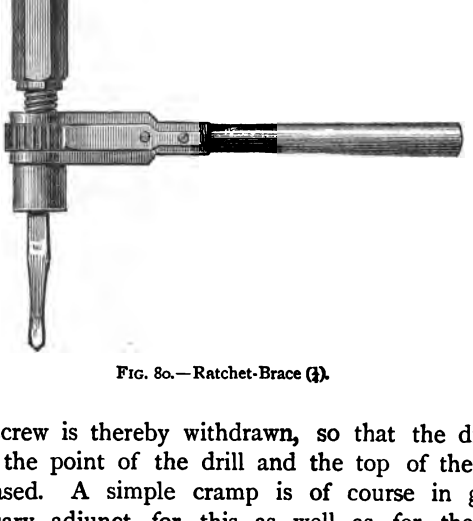

FIG. 80.—Ratchet-Brace (¼).

feeding-screw is thereby withdrawn, so that the distance between the point of the drill and the top of the stock is increased. A simple cramp is of course in general a necessary adjunct for this as well as for the plain brace, but its height can be very much reduced; as can also the distance from any high projecting portion of the work at which the drill can be applied with this instrument.

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After a hole has been drilled, its sides not unfrequently require smoothing, or it may have to be enlarged. For either of these purposes *rimers* or *broaches* are the tools generally used; their forms and their cross-sections, as also their sizes, varying according to the purpose for which they are intended. Two 'taper' rimers are shown in Fig. 81, in which the angles do not exceed 90°, and are favourably placed for cutting rather than for scraping, which is not the case when the cross-section consists merely of a flat-sided figure with five, six, or even eight sides, as it sometimes does. In using rimers of this kind, a very trifling downward pressure is required, for their finely tapered form causes this to be converted into a powerful lateral thrust against the sides of the whole, which in their case constitutes the true feeding pressure. For leaving the side of a hole parallel instead of making it taper, rimers are not unfrequently made of equal diameter for the greater part of their length, the whole of the cutting being then performed by the sharply tapered extremity with which they are provided, the upper portion serving only as a guide. Or a similar effect may be produced by giving them a 'bellied' form and retaining the cutting angles throughout their whole length, but with these the perfect straightness of a hole cannot be secured with equal certainty.

FIG. 81. Rimers.

If a rimer be made, not from a plain conical piece of steel, but from one on whose surface a screw-thread has been previously cut, it is evident that, if its advance at each revolution be equal to the pitch of its screw, it will produce a counterpart of the thread in the interior of the hole through which it is passed.

Internal or 'female' screws are produced by means of *screw-taps*, exactly on this principle. The old method of doing this consisted in applying to the hole which was to be 'tapped' a tapered screw-tap of hardened steel, upon

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the conical surface of which a screw-thread had been previously cut to an equal depth throughout its length, three or four flat facets having been afterwards filed upon it to at least the depth of the thread. Its section thus resembled *a* or *b* in the accompanying cut (Fig. 82), from which it will be evident that—especially in the case of *a*—the exceedingly obtuse angles which they presented were quite incapable of cutting, and could only remove the material from the hollow portion of the thread by a slow scraping action. This, together with a considerable amount of burring or pressing up of the raised parts of the thread, enabled them to operate with tolerable efficiency upon wrought iron and other malleable metals, but with cast iron they were almost entirely incompetent to deal. Under the most favourable circumstances the process was a very slow one, the tap requiring to be worked backwards and forwards several times as each slight advance was made; the full depth of the thread in a nut or in any other 'thoroughfare' hole being attained only when the whole of the screwed portion of the tap had passed through it. Considerable force was necessary to cause the tap to advance at all, and this was applied by means of a long bar or *tap-wrench* with a square hole at its centre, into which the squared upper end of the tap was fitted. But in order to give it sufficient strength, this square portion was made larger than the rest of the tap; consequently, after doing its work, one of these old taps could not be removed from the hole without being unscrewed through its whole length, which entailed much waste of time.

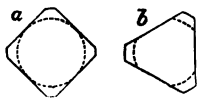

FIG. 82.

Many improvements have been introduced into the hand 'screwing tackle' used at the present day, to the construction and manufacture of which Sir J. Whitworth has devoted much attention. Fig. 83 shows a set of three screw-taps, consisting of a *taper*, an *intermediate*, and a *plug-tap*. A

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cross section to a larger scale—which applies equally to all of them—is also given in the figure; by which the great reduction in the cutting angles and the superiority of their position with regard to the surface to be cut, which results from the adoption of this fluted form, is rendered evident. For in the sections *b* and *a*, Fig. 82, these angles exceeded 120° and 135° respectively, whereas in the present case they are not more than 90°, and the front face of each (the arrow showing the direction in which the tap revolves when working) is radial, so that it can remove the metal from between the threads by a true cutting action, and has no tendency to throw up a burr in the manner mentioned above. The threads upon the taps themselves are cut perfectly parallel throughout, the tapered form of the intermediate and taper taps being given by subsequently taking off the tops of the threads to a greater or less extent. In the former this is only done for a short distance from the lower extremity, but in the latter it is carried to such an extent that the threads are entirely obliterated at the bottom of the tap, a small number of them only at the upper end retaining their full depth. This enables a taper tap to enter a hole of the proper size without difficulty, its first few revolutions doing little more than trace out a thread of sufficient depth to lead it onwards. But by the series of cutting angles which it presents during its advance—each of which to a small extent

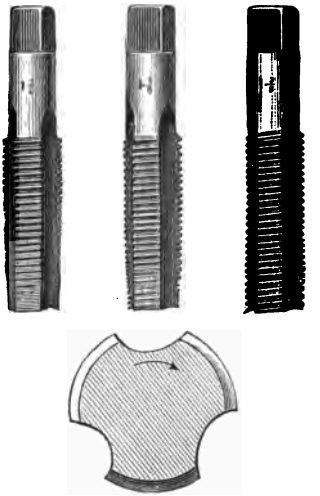

FIG. 83.—Set of Screw-Taps, with enlarged section.

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exceeds its predecessor in height—successive portions are removed from the spiral groove through which they pass, till on its upper end emerging from the hole the tap will be found to have left behind it an almost perfect counterpart of the thread which was originally cut upon its own surface. Any slight inequality which it may possess is then easily removed by following it up with the intermediate tap ; the tedious process of unscrewing mentioned above being now unnecessary, since the more perfect action of these taps enables the force applied to them to be reduced, so that the square head can be made sufficiently small to drop through the hole through which the screwed portion has passed. If the hole be shallow, the operation must be commenced with the intermediate instead of with the taper-tap ; in this case the finishing cut is given with the plug-tap, of which the threads are left of the full depth quite to the extremity.

It should be noticed with reference both to taps and rimers of the above, or any other section with several grooves or flutings—unless, indeed, the proportion of the circumference occupied by the grooves is greatly in excess of what remains—that it is essential to their efficiency for their advancing or cutting angles to project beyond or to be at a greater distance from the centre of the figure than the following angles, which are not required for cutting. If this be not attended to, it is evident that the whole of the concentric portion of the section must be forced into the material before any feed can be obtained ; which, even if it were possible, would cause so great an amount of friction against the interior of the hole that the tool would be broken by torsion before it could be made to revolve. On carefully observing any well-made taps, like those shown in the engraving, it will be seen that on this account the threads, more especially in taper taps, by which the bulk of the material is removed, are always filed off to a much greater extent upon their following than on their cutting angles. Like the rimers of similar section noticed above, they can therefore only cut whilst revolving

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in one direction. In the old flat-sided taps this was not done, and in spite of the circumference being cut away to an extent which greatly endangered the evenness of the thread produced by them, the necessity for forcing these still comparatively large surfaces into the material before any feed could be obtained, had doubtless more to do with their enormous and unnecessary consumption of power than even the unfavourable nature of their angles. This view is confirmed by the much greater ease and efficiency with which six-sided and eight-sided rimers perform their work; for in these, since no part of the conical surface remains, a very much smaller amount of pressure suffices to cause the angles in which their facets meet to enter the work.

FIG. 84. Screw Plate.

In cutting external screw-threads also much improvement has been effected since the days in which the plain *screw-plate* was the only hand-tool used for the purpose. It consisted simply of a steel plate with a number of tapped holes in it, a series of from two to six of which were to be used for each size of screw. These were even less capable of cutting than the early forms of tap just described, the screws being entirely produced by pressing or swelling out of the threads at the expense of the material between them. The diameter of the finished screw was thus generally greater than that of the original

FIG. 85.—Ordinary Stock and Die (¼).

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wire or rod. By the addition of two or more notches to each hole a certain amount of cutting took the place of this violent treatment; and, thus modified, the *notched* screw-plate (Fig. 84) is still much used for small work.

But for larger screws it became absolutely necessary to make the cutting action more perfect, and so to diminish the wasteful expenditure of power which the use of the screw-plate entails. This was done by the introduction of the *stock and dies* (Fig. 85), which enabled one pair of dies first to trace out the thread lightly upon a cylindrical surface, and eventually, by being gradually brought closer together, to cut it to the full depth. Moreover, by making the cavity in the die-stock of sufficient length (as in the engraving), or by various other means, the dies could be easily removed and replaced by others of different sizes. This arrangement, however, is defective, inasmuch as the curvature of the dies must be either too great for them to admit the uncut bar—in which case their outer angles only can act, which, having but little guiding power, are liable to set out a thread which is uneven or 'drunk';—or, as the screw approaches completion, the work is performed more and more by the central portion only of each die. Fig. 86 shows these defects, the curvature of the dies coinciding with that of the finished screw in the upper half of the diagram, and with that of the uncut rod in the lower half. The usual practice is, therefore, to cut the dies with a curvature intermediate between the two, but this is only a partial remedy for the evil.

A much more satisfactory arrangement is that originally devised by Sir J. Whitworth, in which three dies, of small but not of equal width, are substituted for the two wide ones shown in the foregoing figure. As we have seen in the case of screw-taps, the effect of narrowing the concentric portions is to effect a corresponding reduction in the power which must be expended in working them; the necessity for retaining sufficient width to insure the evenness of

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the screw-thread being the chief limit to the extent to which this may be done. In the *Guide screwing-stock*—of which the central portion is represented in Fig. 87—the advantages of efficient guidance combined with great facility of working are obtained by making two of the dies only of small width, and performing the bulk of the cutting with them ; employing the third almost exclusively as a guide to insure the uniformity of the thread. This—the stationary

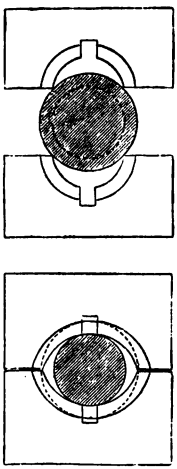

FIG. 86.

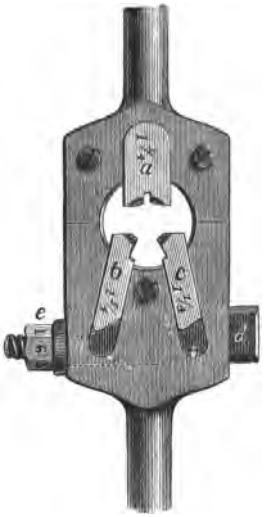

FIG. 87.—Whitworth's Stock and Dies.

die (marked *a*)—is clearly seen in the engraving, as are also the moving dies, *b* and *c* ; the top plate—which to a great extent conceals them when in use, and of which the holding-down screws appear—having been removed for the purpose of showing them. These moving dies are made to advance equally by turning the nut (*e*), by which the inclined portions of the sliding-piece (*d*) are gradually drawn in behind them till the full depth of the thread has been

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attained. Their action, however, is not simultaneous, the curvature of their extremities and their cutting angles being so arranged that one shall cut when the stock is turned in one direction, and the other when it is turned in the opposite one. These dies can be replaced by others for the production of screws of other diameters, and can be sharpened by grinding with the same facility as ordinary tools.

In cutting the threads upon the dies themselves, *Master-taps* are used; one of which is shown in Fig 88. These differ from the ordinary taps shown on a previous page (see Fig. 83), in being of larger diameter (Sir J. Whitworth's exceed the working taps by twice the depth of the thread, which gives perfect contact, and thus produces an even thread at the commencement of the cut), and also in having much narrower longitudinal grooves and a larger number of them, which is rendered necessary by the small amount of surface which the dies present. Similar instruments, known as *hobs*, are also employed in forming the cutting ends of screw-chasing tools for use in the lathe. The importance of possessing and carefully preserving a correct set of master-taps will be evident when it is remembered that the screws produced by the above processes are in all cases mere copies of those already in existence upon the surface of the taps and dies; and that the simplest if not the only practically available method of maintaining the uniformity of these threads—which it is in the highest degree desirable to do—is to have at hand a constant standard of reference by which the effect of continued wear upon the working copies may be detected and remedied.

FIG. 88.
Master-Tap.

So important does Sir J. Whitworth consider the subject of the uniformity of screw-threads—not only of those made in a single workshop or for one particular purpose, but of all to which a fixed pitch can be applied throughout

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the whole country—that he arranged and published, partly in the year 1841 and partly in 1857, a table, the use of which, for machines and engineering work, has been gradually extending with most beneficial results; the excessive loss and inconvenience which arose from the absence of any standard pitch being now universally acknowledged. (See Appendix, Table IV.)

For the threads of small screws, to which this table did not extend, a supplementary table has since been proposed, which also will be found in the Appendix (Table V.)

The angle made by the opposite sides of the thread is 55° in every case, but the extreme depth which this angle would give is reduced by rounding off the top and bottom, each to the extent of one sixth, as the diagram (Fig. 89) will explain. Thus the depth given to the thread is only two thirds of that which it would have if its sides intersected, being ·64 of the pitch instead of ·96.

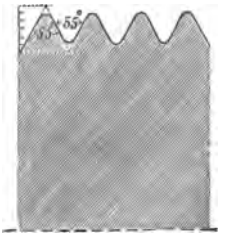

FIG. 89.

Square-threaded screws, which are used for many purposes, since they possess greater power, although less strength than those of the above form, have generally half the number of threads per inch than would be given to them if the threads were angular, the depth being usually equal to the space between the threads. When coarse, however, they should be deeper in proportion than when they are fine.

For many purposes—such as screws cut on the outside or inside of tubes—much finer threads, in proportion to their diameters, than those given in Table IV. are required. In these there has hitherto been much less uniformity than could be wished, although the immense consumption of metal tubes for the distribution of coal-gas has caused some such threads to be pretty generally recognised, under the name of *gas-threads*. In the Appendix will be found two further tables, the first giving the pitches used by Sir J.

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Whitworth in his taps and dies for gas-piping, and the second the coarser pitches admissible in the case of the stouter piping used for hydraulic purposes. (See Tables VI. and VII.)

These tables, however, must not be supposed to apply only to the forms of apparatus which we have been describing,—for this would confine their use within very narrow limits, since but a small proportion of the screws in daily use are cut by hand with their assistance. For the production of many kinds, indeed, stocks and dies, even of the best construction, are much less well adapted than are other instruments, some of which we shall have occasion to describe hereafter; amongst which may be mentioned hand-chasing tools, screw-cutting lathes, bolt-screwing machines—all of which have their special advantages.

The *Smith's Saw* (Fig. 90) demands no particular notice except perhaps as regards the manner in which the small

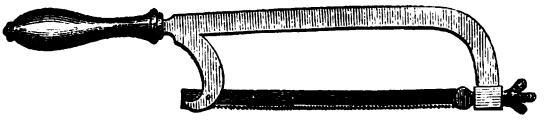

FIG. 90.—Smith's Saw.

amount of 'set' necessary for leaving clearance in the cut is given to it. This is done by lightly hammering the points of the teeth. Subsequent sharpening with a three-square file converts the blunted points into chisel-like edges slightly wider than the original thickness of the blade.

Several of the hand-tools used for metal fulfil their duties by what we cannot regard as a true cutting action. Such are the various *Punches* and *Shears* by which portions of the material are removed, which, instead of being waste products, as in the case of cutting tools generally, constitute that which it was the end and object of the operation to obtain.

The term 'punch' is made to include two very different

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kinds of instrument. Of one of these the chief duty is to indent the material to a greater or less extent, without absolutely dividing it;—examples of which are to be found in the pointed centre-punch, the various thick-edged circular and other punches with which thin discs, &c., may be partially cut from sheets of metal, and also in the ordinary cold-chisel, when used for nicking sheets or bars of moderate substance. But these cannot be driven through the entire thickness of the material, and therefore cannot be considered to cut it, unless it be placed upon some hard and ponderous mass, such as an anvil, by the reaction of which they are then assisted. In the accompanying diagram (Fig. 91), *a* represents in section a tool of this description partially driven through a sheet of metal which rests upon the hard surface of an anvil. The difference between this and a punch of the second kind (*b*)—which must be used in conjunction with a *bolster* placed beneath the work, and is thus precisely analogous in its action to the pair of shear-blades (*c*) is at once apparent; since in these cases the portion of the tool which is below the work is almost exactly similar in figure to that which is above it, and, except when prevented by extraneous circumstances, such as inequality in their areas, each performs an equal share of the work. It is evident, however, from the obtuseness of the edges in both cases, that the division of the material is effected by tearing its fibres apart rather than by cutting them fairly asunder; and this is equally true of the upper and lower blades of a pair of shears, and of the punch and bolster, which may be regarded as similar blades of a circular or other figure.

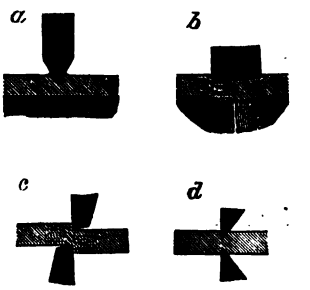

FIG. 91.

Two pairs of *hand shears* are represented in Fig. 92.

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The upper one of them is the ordinary form of ***English hand shears***, which are often called snips, to distinguish them from the fixed-bench shears used for metal of greater thickness than can be cut when the tool is merely grasped in the

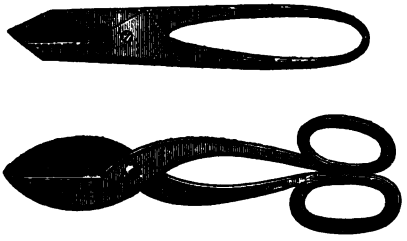

FIG. 92.—Hand Shears.

hand, their blades being occasionally bent instead of straight, for greater convenience in cutting out curved work. The lower pair, provided with bows like scissors, is of that known as the *Scotch* pattern.

For cutting wires, &c., a modified form of shearing tool is sometimes employed. Opposite the pivot in each half of a pair of single-jointed nippers a notch is cut. These notches coincide with one another when the nippers are open, so that a wire can be inserted into them. On closing the nippers, the wire is easily and cleanly divided. But these tools are but little used, either the *cutting nippers* or the *cutting pliers* shown in Fig. 93 being ordinarily employed for the purpose. In these, although the direction of their edges is different, the cutters are alike, the section *d* (Fig. 91) applying equally to both of them. From this section it will be perceived that their action differs entirely from shear-

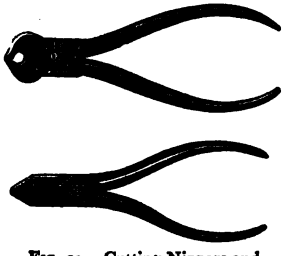

FIG. 93.—Cutting Nippers and Pliers (¼).

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ing, their edges, although perfectly similar, being merely two opposed wedges which can be brought together till they meet, but which cannot pass each other, after the manner of shear-blades; consequently their angles are very much more acute, being from 30° to 40° instead of from 80° to 90°, to which the edges of shear-blades for metal are generally ground.

Of the use of punches combined with bolsters—which we have been obliged to introduce above—it is hardly possible to give an example without trespassing into the province of machine-tools. For their performance clearly depends upon exact correspondence being obtained between the position of the punch on the upper side of a plate and that of the bolster (or *die*, as it is called when applied to the larger forms of punching machine) on the under side. Various kinds of holder, by the upper part of which the punch shall be guided when driven, whilst the lower either receives or itself forms the bolster, may be and possibly are employed; but some form of machine, in which both the punch and die can be fixed, and powerful pressure can be applied, add so greatly to their value that they are almost invariably so used in engineering workshops. The simplest and most portable of these hand-machines is the *punching bear* (Fig. 94), which is, in fact, a powerful form of screw-press—by which plates of considerable thickness can be perforated by hand power. One man, applying his strength at the extremity of a lever passed through the eye of the screw, is able with this instrument to punch a hole as much as $\frac{3}{4}$ of an inch in diameter through a plate $\frac{5}{8}$ of an inch in thickness; and other equally powerful forms of apparatus are made.

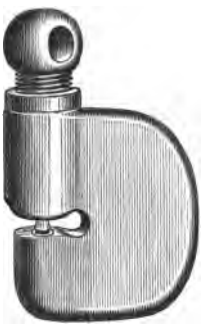

FIG. 94.—Punching Bear.

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A tool which lends invaluable assistance to the hand-worker in metal, though it may be sought for in vain in many tool manufacturers' lists, is the *Scraper*, one form of which is represented in Fig. 95. It is made simply by widening out and bending down the end of a flat bar of steel—an old flat file being often used for the purpose. The

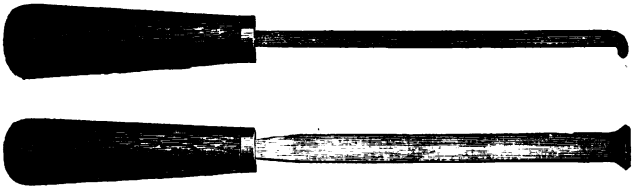

FIG. 95. - Metal Scraper.

bent end is ground so as to form a thick knife-edge (of about 60°) at right angles to the stem of the tool, and the edge is afterwards set on an oilstone—at the same angle if intended for taking as deep cuts as possible, or at 90°, or even more, if required for lighter or finishing cuts. The enlarged view, Fig. 96, shows the edge ground at 60° and set at 90°. The method of using it will be noticed in the next chapter.

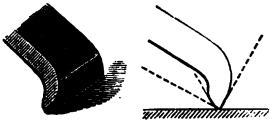

FIG. 96.—Edge of Scraper.

FIG. 97.—Three-Square Scraper.

A good substitute for it may be made by sharpening the extremity of a three-square file, the angles of which being 60°, can all in turn be used for scraping, in the manner indicated in the diagram, Fig. 97.

Materials of which the hardness exceeds, or even nearly equals, that of hardened steel, cannot be treated by steel cutting-tools such as we have been describing. Some harder

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substance must then be resorted to, the most readily available being corundum, or emery, which may be employed in various ways. If two corresponding surfaces can be operated upon simultaneously, the emery, powdered and reduced (by washing) to as even a grain as possible, may be simply placed between them with a small quantity of oil, the two surfaces being then ground together. But this practice is by no means to be recommended, for several reasons: (*a*) the action cannot be confined to the portions of the surfaces which require to be reduced; (*b*) unless opposite portions of each require an equal amount of treatment, correction of the errors in one introduces fresh errors into the other; (*c*) in almost every case, whether the surfaces be flat or curved, their speed is greater or their contact is of longer duration in some parts than in others, so that grinding does not take place uniformly even between surfaces originally true; (*d*) the emery becomes embedded in the metal, so that sliding or other 'working' surfaces so prepared carry in them an element tending to their own destruction. When emery has to be used by hand at all, it is therefore preferable to employ it in some other manner, as in the form of *emery-paper* or *emery-cloth*, which can be wrapped round a file or round some suitable wooden support, so that its action is more or less under control. These also are often used with oil, which improves the smoothness of their cut, though it dulls the surface of the work. For some purposes, again, *emery-sticks* are preferred, the powder in their case being glued directly on the surface of strips of wood instead of on paper or cloth.

A metallic wheel or 'lap' is a very efficient means of employing emery powder, but these require a lathe or some form of machine for driving them, and, therefore, do not come within our present subject. The same may also be said of the consolidated *emery-wheels*, of which some description will be found in a subsequent chapter.

The marks by which the different degrees of coarseness

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of emery-cloth are ordinarily distinguished in London are :—No. 0, No. FF, No. F, No. 1, No. 1½, No. 2, No. 2½, and No. 3 ; the first of these being the finest, and the last the coarsest. Emery powder itself is sold under the following names, commencing with the coarsest, of which the grain is about the size of mustard seed :—

Corn emery.
Coarse grinding emery.
Grinding emery.
Fine grinding emery.
Super-grinding emery.
Coarse flour emery.
Flour emery.
Fine flour emery.
Superfine flour emery.

The other abrasive materials used in the treatment of metallic surfaces are not very often to be met with in engineering workshops. They are chiefly confined to the arts, in which smoothness of surface or 'finish' is a more important consideration than accuracy of form, and they are less frequently applied to wrought or cast iron than to brass and similar metals. Strips of oilstone, or of Water of Ayr stone, may occasionally indeed be employed for removing the marks of the file or for producing the 'curled finish' with which flat metal surfaces are sometimes ornamented, but for working surfaces—upon which the chief care should be bestowed—this treatment is neither necessary nor desirable.

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CHAPTER IV.

ON THE FORMATION OF STRAIGHT-EDGES AND SURFACE-PLATES.

BESIDES the measuring instruments and the cutting tools already mentioned, various forms of apparatus are required to enable the worker in wood or in metal to test the accuracy of his operations. For this purpose the former has recourse to the straight-edge, square, bevel, &c.; while the latter, in addition to these, uses templates of various kinds, and—above all—the planometer or *surface-plate.* The importance of this last instrument (examples of which will be found in Figs. 103 and 105) is so great that we shall devote much of this chapter to the consideration of it; especially as the successive steps in its production will afford a good illustration of the modes of using several of the wood and metal tools previously noticed.

In the year 1840 Sir J. Whitworth called the attention of the scientific world to the impossibility of producing truly plane metal surfaces by the process of grinding, by which up to that time it had almost invariably been attempted, and he showed some specimen plates, which, for accuracy of surface, far surpassed any which had been publicly exhibited previously.

To give some idea of the agreement which exists between two of Sir J. Whitworth's surface-plates, we may mention that if one of them be placed upon the other—both being perfectly clean and dry—the upper one will appear to float upon the lower, without being anywhere in contact with it; owing to the weight of the upper plate being insufficient to expel, except by slow degrees, the thin and uniform film of air between their surfaces. When this air has been expelled (as it may be by pressing and sliding the plates together), they will adhere to one another to a sufficient extent to enable the lower plate to be lifted by

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lifting the upper one ; a result partly due to a cause similar to that which produces the floating just mentioned, and perhaps partly also—as some recent experiments upon surface-plates *in vacuo* by Professor Tyndall are considered to prove—to the force of molecular attraction.

Before commencing upon any cast-iron or other plates whose surfaces it is intended to convert into true planes, two preliminary steps must be taken : in the first place, two wooden straight-edges must be prepared ; secondly, with the assistance of one of these, a set of three steel straight-edges must be worked up. When these have been made to agree perfectly with one another the surface-plates may be commenced ; the principle of obtaining exact agreement between a set of three of these being always adhered to. In general, of course, the possession of an existing surface-plate, or at least of a fairly reliable straight-edge, will obviate the necessity for performing some of these operations ; but we prefer to give them in their entirety, noting afterwards those which the ordinary appliances of the workshop would enable us to dispense with.

First, then, as to the *wooden straight-edges*; the preparation of which will require some skill in the use of the joiner's

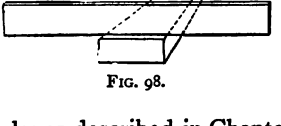

FIG. 98.

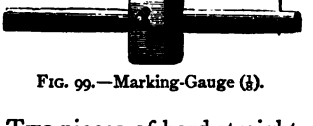

FIG. 99.—Marking-Gauge (½).

planes described in Chapter II. Two pieces of hard straight-grained mahogany not less than three feet long and a quarter of an inch thick having been selected, and both sides of each having been roughly planed over with a jack-plane, the first care must be to see that they are not 'in winding' —as a joiner expresses it when two of the opposite corners of a piece of wood stand higher than the other two. This is most easily detected by placing two short pieces of wood

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with parallel edges, called *winding-sticks*, in the position shown in Fig. 98. On bringing the eye nearly into the line of their upper edges, so as almost to make the nearer conceal the more distant one, this error, if it exists, at once becomes visible. After each side has in turn been corrected, one of them should be worked up with a finely set trying-plane until a continuous shaving can be cut from the full length of the piece. If the plane be in good order, and the caution previously given as to planing 'hollow' rather than 'round' be not neglected, this side will be found to be sufficiently flat.

From this flat surface the desired thickness must be set off at each end with a *marking-gauge* (Fig. 99); the scratch which it leaves indicating the amount to be planed off the opposite side. This done, the edges may be commenced; the process being similar to that by which the sides were made true, but requiring to be conducted with increased care.

The *square* (Fig. 100) will now be necessary to insure the edges being kept perfectly perpendicular to the surface first obtained—which surface should be marked, and always be worked to. One edge of each piece having been then planed as true as possible, their agreement with one another must be tested—first, by observing whether their contact is continuous when they are placed edge to edge and held up towards the light; secondly, by clamping them side by side with their true edges upwards and trying with the fingers whether one edge

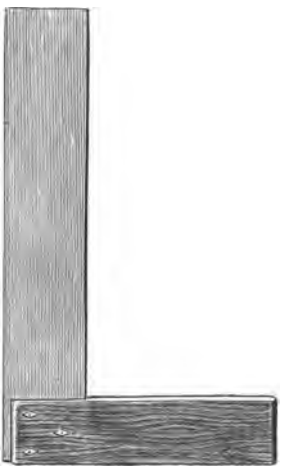

Fig. 100.—Carpenter's Square (⅛).

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stands to any sensible extent above the other at either end or at any intermediate point. (A still better system is to make three straight-edges, each of which must agree with any other, as described below; but the material not being susceptible of any very great degree of accuracy, it is hardly necessary.) The best result only being obtained when the final cut has been taken from the whole length of the straight-edge, no after-treatment of any kind should be required. But in default of his having the requisite skill, the beginner can with advantage make use of the cabinet-maker's scraper, or—which is much better—a flat piece of cork covered with fine glass-paper.

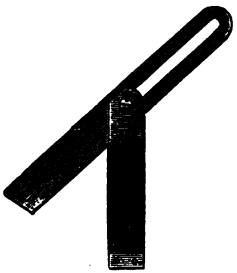

FIG. 101.—Sliding Bevel (⅛).

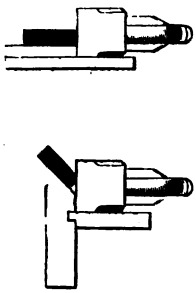

FIG. 102.—Shooting-Boards.

Applying the square to the true edge, the exact length is now marked off, and the ends cut and planed or 'shot' from the finished to the unfinished edge. Finally, this second edge is marked out with the gauge, planed up, and chamfered if required; the uniformity of the chamfer being checked by applying to it a *sliding-bevel* (Fig. 101) which has been previously set to the proper angle.

In this last operation, and also in planing the ends or edges of thin pieces of wood generally, much assistance may be derived from the use of *shooting-boards*. Fig. 102 shows sections of such boards, one of them being intended for planing pieces with square, the other with chamfered or bevelled edges. The trying-plane is laid on its side and

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worked backwards and forwards with one hand, the work being brought up to it with the other.

The second step—viz. the preparation of three accurate *steel straight-edges*, can now be proceeded with. And although we shall confine ourselves to steel, as being the best material for our present purpose (and for straight-edges generally, provided that their length does not exceed about 4 feet), a somewhat similar course will apply to the working up of longer ones, which would be made of cast iron. The thickness of those which are of steel is usually from $\frac{1}{16}$ of an inch to $\frac{1}{2}$ an inch.

Three similar strips of steel of the desired size having been procured, and their sides filed or smoothed upon a grindstone, holes should be drilled in similar positions near the two ends of each of them. When the strips are laid one upon another, two tightly fitting pins can then be passed through these holes; in which condition the three will resemble a single thick bar. They can be fixed in a vice, and—as far as all the earlier stages are concerned—may be operated upon simultaneously.

The ordinary vice has appeared in a former engraving (Fig. 79). The teeth with which its jaws are filled can in cases like the present be prevented from marking the work held between them, by interposing *clamps*, formed out of pieces of sheet lead or zinc. In filing up the steel straight-edges great assistance will be derived from one of the wooden ones previously made, which should be rubbed with a piece of red chalk, and frequently applied to them; any prominent parts being thus rendered visible. The large rough files used in the earlier stages must be successively replaced by smaller and smoother ones as the work progresses. When it becomes no longer possible to detect any inequalities on applying the wooden straight-edge, the pins connecting the three pieces must be removed, and all further operations conducted upon each of them separately. But before this point has been reached, one edge of each should be bevelled,

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if required, as the straightness is liable to be impaired by the process.

A systematic course of comparison of one with another must now be commenced, and be persevered in till each edge agrees perfectly in any position with the other two. The necessity for operating upon three (the method above given for wooden straight-edges being insufficiently accurate for steel ones) is evident if we consider that two may agree perfectly together, although one may be convex or 'round,' and the other concave or 'hollow.' When their ends are reversed they will also agree, if the curvature be uniform. But if there are three (which we will call A, B, and C), then if A be hollow, B and C when made to agree with it will both be round, so that they cannot agree together. They will, in fact, make the error appear to be twice as great as it really is, and in order to correct it an equal amount must be removed from each, until perfect agreement is obtained between them. Then, on correcting A till it agrees with B, the correspondence, or the want of correspondence, between A and C will prove their mutual truth or error. By persevering and systematic repetition of these comparisons, good results will at length be obtained. And in addition to placing the two which are under comparison with their edges together, and observing whether any light can pass between them, it will be found advantageous to lay them side by side on a flat table or bench, and to rub their cleaned edges somewhat forcibly together. Any prominent parts will then receive a slight burnishing, which will show where the file must be applied.

When one edge of each piece has thus been rendered straight, the opposite one may be similarly treated; their approximate parallelism being obtained, when necessary, by the frequent use of callipers during the operation. Of these instruments one example has already been given, and others will be found in a subsequent chapter (see Fig. 160). A simple and very efficient substitute for them may be made

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by filing a parallel-sided notch, of the exact width required, in a piece of sheet metal. This forms a temporary gauge of no mean accuracy when carefully used; a second notch of slightly greater width, to show when the desired limit has nearly been reached, being a useful addition to it.

Having now at least one thoroughly reliable steel straight-edge, we are in a position to commence the *surface-plates* themselves. Three sound cast iron plates are required, and whatever their size may be—for this will, of course, vary according to the purpose for which they are intended — they must have no tendency to bend or become distorted during their preparation, or in after-use. To fulfil these conditions it is necessary to support their under-sides by deep main and cross ribs. If, however, the main ribs were to follow the rectangular outline of the plate, there should be a support at each of the four corners, and any inequality of the bench or other surface on which it was placed would make these bear unequally, and would be liable to distort the plate. Sir J. Whitworth therefore devised the plan, now universally adopted, of reducing the number of supporting points to three, and arranging the main ribs between them in the somewhat triangular form shown in Fig. 103. Upon the three supporting points the roughed-out castings should rest for two or three weeks before the finishing processes are commenced, in order to allow the plates to settle in the form which they will naturally assume.

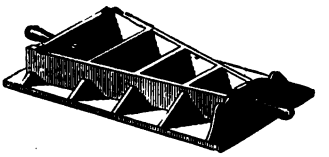

FIG. 103.—Surface-Plate.

Supposing a planing machine not to be accessible, the upper surface of each casting must be prepared with a chipping chisel and hand file, during which operations the chalked wooden straight-edge will render much assistance in pointing out the more prominent portions, just as it did in the preparation of the steel straight-edges. It must of

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course be applied to all parts of the surfaces, diagonally as well as parallel to the edges. Or a rectangular piece of hard wood, planed as true as possible, may be substituted for it with some advantage. But either of them must soon be rejected in favour of the much more accurate steel straight-edge, which can either be held so as to show any depressions by the passage of a streak of light between its edge and surface, or be made to redden the projecting parts by smearing it with a mixture of red ochre and oil. Moreover, inasmuch as files of considerable length only

FIG. 104.—Method of holding Scraper.

can be used, which cannot be made to remove small portions from particular spots, as can be done in the case of a narrow straight-edge, to which very light and smooth files can be applied, it soon becomes necessary to substitute a scraper. With this tool very small quantities of metal can be taken off at any required point, so that a tolerably flat surface will soon be obtained. Fig. 104 shows the method of using this invaluable instrument.

One of the castings only should be worked up to the highest state of perfection obtainable with the steel straight-

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edge and scraper, the care bestowed upon it being repaid with interest during the subsequent processes. This plate we will call A, the others respectively B and C. The face of A is now thinly coated with ochre and oil, B and C being successively made counterparts of it by repeatedly placing them face downwards on A, and then lowering with the scraper all the reddened points on which they bear. This must be continued till the contact between A and B and A and C is as perfect as possible, which will be known by the bearing points—at first perhaps only two or three in number, and of small size—having become so numerous and evenly distributed that the entire surface presented by them becomes reddened.

A series of comparisons exactly similar to that described in the case of the steel straight-edges must now be carried out :—B and C being compared together, and corrected by removing an equal quantity from each ; A being then made a counterpart of B, and A and C compared with one another. If B and C have been perfectly equally reduced (and to effect this the greatest care will be well bestowed) their errors, which are equal in amount and similar in kind, will have been entirely got rid of, and A will be found to agree with C, thus proving all three of them to be true planes. But it is not likely that this result will be obtained till the above routine has been many times repeated, in doing which the same order should always be adhered to. As the process approaches completion increased watchfulness will be necessary, so as to guard against the introduction of fresh errors ; the penalty for scraping off the slightest excess from any one part being the performance of the difficult task of lowering the entire surface to exactly the same extent.

When all possible care has been taken, it must not be expected that the surfaces produced will be absolutely true —mathematical accuracy probably could not be maintained even if it were possible in the first instance—but the approximation to it will be sufficiently close for every practical

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requirement. The abandonment of the whole process of alternately grinding together with emery-powder and water the faces of a set of surface-plates, has been accompanied not only by the most marked improvement in their accuracy, but also by a diminution in the time expended upon their production. Soon after he had thus successfully produced his surface-plates, Sir J. Whitworth entirely abolished in his own workshops the practice of grinding metallic surfaces together; and although his workmen were considerably prejudiced in favour of it, a very short experience taught them that scraping was by far the quicker and more efficient process.

Three surface-plates having been successfully 'originated' in this manner, two of them should be kept with scrupulous care for the correction or production of copies of sufficient accuracy for ordinary workshop purposes. Once in possession of a reliable standard, the process of copying it involves a comparatively small tax upon the patience and skill of the operator. Not only is he no longer dependent upon an accurate straight-edge—he may if he can avail himself of a planing-machine, dispense with the whole of the roughing-out process above detailed. With these invaluable machines—which are described in the sequel—the surface of the rough casting can be brought to such a comparatively finished state that it may be at once compared with the standard surface-plate. This being kept thinly and uniformly reddened, will show the prominent parts, to which the application of the smooth file, and subsequently of the scraper, must be confined, as already mentioned.

Fig. 105 represents very fairly well the face of a small six-sided surface-plate finished by scraping in the manner shown in Fig. 104—the particular size and form of the final cuts varying of course according to the fancy of the workman. Plates of this shape, strengthened at the back by two annular ribs, are stated by Sir J. Whitworth to be preferable to rectangular ones, such as Fig. 103.

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Long straight-edges, which—as stated above—are generally made of cast-iron, require to be so constructed as not to be liable to flexure from their own weight when in different positions, nor from that of any articles which may be placed upon them for comparison. A straight-edge six feet in length is represented in Fig. 106 in elevation and

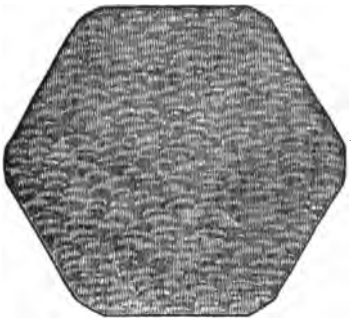

FIG. 105.—Scraped Face of Surface-Plate.

plan. The width of its face is $2\frac{1}{4}$ inches; cast iron straight-edges being always much wider than steel ones in proportion to their length. Those which are 10 feet long have a width of as much as 3 inches, so that they resemble

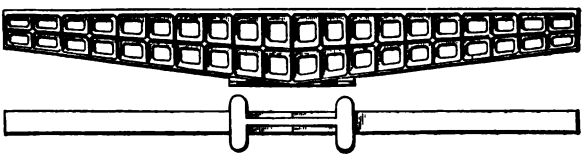

FIG. 106.—Six-foot Cast-iron Straight-Edge.

elongated surface-plates, and their preparation requires much greater time and care than is necessary in the case of those of small width with which we have been dealing. For with regard both to straight-edges and surface-plates, it will be readily understood that any given length or area is

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worked up with far more facility when it does not form part of a much greater length or surface than when it does.

For special purposes surface-plates of special shapes and sizes are often required, and for extending a plane of great area a good sensitive level is used in conjunction with them.

The use of a good surface-plate to the worker in metal is sufficiently obvious. It enables him, either by following the whole process for obtaining a true counterpart of its surface, to give almost perfect accuracy to the flat facets which occur on the exterior of his work, or, by completing the early stages only, to render them perfectly free from twist and prominences, though not necessarily from depressions. A good fit may thus be insured between the several portions of a machine which are to be attached to one another, with an amount of labour which bears but a very small proportion to that required for 'facing' a slide-valve, or any other moving parts. When several surfaces of moderate size have to be worked up on the same casting or forging, it is advisable in the first place to rough out the whole of them with moderate accuracy, afterwards finishing them in the order of their size. The largest, from which the correct position of the other surfaces should almost always be determined, will thus be first completed. If there be a second surface parallel to it, this should next be marked out, either with a gauge of similar construction to the wooden marking-gauge shown in a previous figure, or with a *surface-gauge* (Fig. 107), used on the surface-plate. In a similar manner the truth of the edges—if they be at right angles to the face—can be tested conveniently by placing the work, face downwards, upon the surface-plate, and applying to it the exterior angle of a steel square, which for this purpose should have a wide back, so as to enable it to stand upon the surface-plate.

But these methods of forming flat surfaces either parallel or at right angles to other existing surfaces are available only

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when no very high degree of accuracy is required. In cases for which they are insufficient it will be necessary to follow them up with treatment of a very different kind.

We will suppose, for instance, that three bars of rectangular section are to have their sides and ends worked up sufficiently truly plane and parallel to enable them to be used as standard measuring bars; and less than three cannot be successfully treated. With the assistance of one of a pair of surface-plates—of which the size must be sufficient to admit of the three bars being placed upon it simultaneously—one side of each bar is made as truly plane as possible, and upon these finished sides the three are then laid in the first position shown in Fig. 108. The opposite sides, which will of course have been made nearly flat and

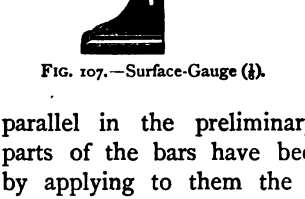

FIG. 107.—Surface-Gauge (¼).

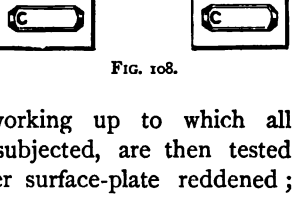

FIG. 108.

parallel in the preliminary working up to which all parts of the bars have been subjected, are then tested by applying to them the other surface-plate reddened; their prominent parts which receive the colour being successively lowered in the ordinary way, till the whole of the surfaces are proved, by being uniformly coloured, to be in one and the same plane. If this plane be perfectly parallel to the surface upon which the bars are resting, they will be equally and uniformly coloured on applying the upper surface-plate, after turning the central bar (B) end for end (as shown in the figure), or after changing the places of A and B, or B and C. But if each bar either has one of its edges or one of its ends higher than the opposite one, the reddened plate will no longer take its bearing upon the

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entire surfaces; and the treatment must be continued—scraping away the coloured portions, then changing their positions from side to side, and reversing them end for end—until the entire surface is reddened, in whatever position the bars may be placed. This, as might be expected, is often a work of very great labour, especially when, after making them parallel, one of these sides has to be uniformly lowered in each bar in order to make the thickness correct. This thickness can best be tested with the aid of a measuring machine.

The next step will be to make one of the remaining sides of each bar perfectly perpendicular to the two sides which have just been rendered parallel, and the method of doing this will be intelligible from Fig. 109. One side (we will say of the bar A) is first brought to a true plane in the ordinary way. A second bar (B) is then similarly treated, its exact correspondence with the first being insured by frequently comparing them together in the manner shown in the first portion of the figure, the side of A being reddened to show the extent to which the two are in contact. When their agreement is perfect, one of the bars must be reversed; the effect of which will be, if their former plane of contact was perpendicular to the horizontal surfaces, to leave their agreement as perfect as before, but, if not, to make the error appear to be twice as great as it really is, as is represented (greatly exaggerated) in the second half of the diagram (Fig. 109). Equal amounts must then be removed from the prominent portions of these sides, until their contact is found to be perfect in either position. One side of the third bar can be made correct by testing it with either of the other two, after which the fourth side of each must be made parallel to that which is opposite to it, and the thickness corrected as before.

FIG. 109.

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We have thus worked up the whole of the sides to the condition of plane surfaces truly at right angles to one another, the bars being now 'die-square,' as it is termed, throughout their length. It only remains to reduce to the same conditions the end surfaces—which in the bars under consideration are turned down from a square to a circular form. For this purpose there will be required, in the first place, a small surface-plate, called a 'trial plane,' and, secondly, a cast-iron bed, having on its upper surface a V-groove, of which the sides are truly plane, and at right angles to each other. The end of the bed must also be made approximately perpendicular to the direction of the groove. One of the bars being laid in this groove—and throughout this part of the process each is treated quite

FIG. 110.

independently of the other two—the trial plane is applied to the end of the bed in the manner shown in Fig. 110. If it is found that, whilst the reddened trial plane is held firmly in this position, a portion only of the end surface of the bar is coloured by it, scraping must be had recourse to and be continued till coloration of the entire surface proves it to be in one and the same plane with the extremity of the bed. On now laying the bar upon those which before were its upper sides, perfect coincidence with the end plane of the bed will obtain only if this plane be truly perpendicular to the axis of the bar. Any departure from this direction will be rendered evident by a portion of the surface only being coloured, owing to the imperfect contact which the right-hand

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portion of the above figure so plainly shows. This must be corrected by scraping the ends of both the bar and the bed.

Where numerous bars have to be worked up die-square to exactly the same dimension, a surface plate or 'trial plane,' used in conjunction with a bed or block of the form indicated in Fig. 111, greatly facilitates the operation. Each bar can then be treated independently, the parallelism of its opposite sides being proved by uniformity in the bearing of the surface-plate on the bar and on the block, when in the position shown in the engraving, and the squareness of the bar by any two of its adjacent sides being simultaneously in contact with the two sides of the groove. Uniformity in the thickness of successive bars is also insured by this method, so that any number of copies of a standard bar can thus be made perfectly true as regards their cross section, without the employment of a measuring machine.

FIG. 111.—Block for testing Square Bars.

A bed of this kind is, however, of but little service except for cubes or bars of the exact size for which it has been made, and its preparation demands so much care and skill that the gain resulting from its use is not great, except when a considerable number of such articles have to be squared to precisely the same cross section. In preparing such a bed it should be remembered—first, that a bar can fit the groove perfectly in all positions only if all its adjacent sides, and therefore also the sides of the groove, are truly at right angles to each other; secondly, that any error in the direction of the inclined surface can be detected by turning the bar end for end when testing it with the trial plane, as in Fig. 111.

When the sides or edges of a piece of work are inclined

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instead of being perpendicular to a previously formed surface, the correctness of the inclination can be tested approximately by means of a bevelled square, set either permanently or temporarily to the proper angle, and used either with or without a surface-plate. But a more usual method is to prepare a *template*, by cutting out a piece of stout sheet metal to the converse of the required form. Templates are also much used in working up curved or irregularly shaped surfaces. When many of these have to be worked to the same curve or angle, a pair of templates, called respectively a male and female template, is generally made in the first instance. Each of these is the counterpart of the other, their perfect agreement being tested by holding them up against the light —none of which should pass between their edges. Any deterioration in the form of the one which is applied to the work can then be at once detected by comparing it with the other. But in the treatment of the flat portions of any piece of work, whatever may be their positions with regard to each other, templates alone should not be relied upon. The relative positions of the surfaces having been established by such means, their flatness should always, if possible, be checked either by applying them to a surface-plate, or, if the work itself is not readily movable, by lifting the plate and applying it to them. When the weight of the surface-plate forms an obstacle to detecting the position in which it bears freely on the surface to be tested, relieving the hand by suspending the plate from above will be found to be of assistance.

If any reader of this volume, anxious to improve in the hand-working of metal to an extent sufficient to enable him successfully to carry out the above instructions, should ask for some measure by which he could gauge his own progress, we could point to no better one than the amount of skill in the use of a file to which he had attained. A few hints on the subject may, therefore, be acceptable, although the artis one which can be thoroughly acquired by practice only.

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Files, inasmuch as they differ from cutting tools generally in being incapable of being sharpened, demand greater economy in their use. On this account, a new file should always, if possible, be first used upon brass or cast iron, for with these metals a blunt file is comparatively useless; afterwards upon wrought-iron or steel, which do not require similar sharpness. On the same grounds it will be found advantageous in all cases to use as rough a file as circumstances will permit.

The outer 'skin' of cast iron is exceedingly destructive to file teeth. In the rare cases in which it is necessary to attack it with a file, one which is too blunt for other work should be employed, but it seldom happens that the surface cannot be prepared to some extent, either by planing, chipping, pickling, or grinding upon a grindstone or emery wheel. The last of these processes is much to be recommended on economical grounds—not only for castings from which much of the material cannot be spared, but also for taking off the 'scale' produced by the superficial oxidation of wrought-iron when being forged, which is also to some extent injurious to a file. Brass castings, although they are not hardened by the chilling effect of a sand mould like those of cast iron, must also have the sand which adheres to them removed by pickling or by cleaning them with an old file before a sharp one can be used upon them with impunity. Lastly, the operator should remember that a file will not long continue keen if he allows it to come into contact with the jaws of the vice in which his work is so frequently supported.

The chief cause of the greater difficulty in handling which the file presents to a beginner, as compared with the generality of cutting tools, lies in the small amount of guiding power which it possesses in proportion to the accuracy of the work demanded of it. Since its whole surface consists of a series of cutting edges or points, it is evident that those which are in action at any one time will perform equal

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shares of the work only when a perfectly equal 'feeding' pressure is applied to each of them. In the due proportioning of this pressure lies the whole secret of success.

Let us consider how this must be effected when it is required to file upon a piece of metal of small width a face perfectly flat and parallel to its existing face. Its section and that of the file teeth in contact with it—both much enlarged—are represented in Fig. 112. In order that the successive cuts may be straight and parallel, it is necessary that the pressures A and B be constantly equal, an equal quantity of the material being then, and then only, removed by each tooth. But—assuming the handle of the file to be held in the right hand and its point in the left—during each stroke the leverage at which the pressure applied by each hand is acting is constantly varying; the right hand having largely the advantage at the commencement, and the left at the end of the stroke. So the effect of the natural tendency to equalise as much as possible the pressures applied by the two hands is, at first, to force into the work the teeth on the side B, almost neglecting those at A, gradually to diminish this inequality on approaching the centre of the stroke, and again to increase it in the opposite direction, after the central point has been passed. Consequently, as is shown in an exaggerated manner in Fig. 113, the side B at the commencement, and the side A at the end of each stroke, will be filed away to too great an extent—a convex surface being thus produced instead of a flat one. Until he has

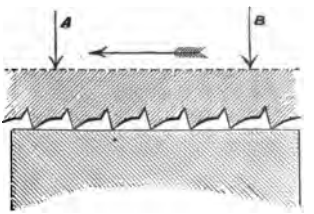

FIG. 112.

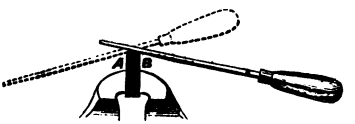

FIG. 113.

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completely overcome this tendency, which practice alone will enable him to do, the beginner should not rest satisfied with his performance. By carefully feeling for the position at which the file bears evenly upon the whole surface which it covers, and checking its disposition to tilt upon either edge at any part of the stroke, he will gradually acquire the habit of moving his hands in the nearly horizontal line required, and so varying the pressure applied with each that it shall be constantly uniform on all parts of the work.

The case of filing a narrow facet, such as we have been considering, although it affords a good illustration of the difficulty of handling a file, is not to be recommended for practice till considerable success has been achieved with rather wider surfaces. For this purpose the best width is from about one inch to four inches, according to the size of the file and the capability of the operator. But whatever its size, the work should always, if possible, be so fixed that the surface which is to be filed shall be horizontal.

Wide surfaces—those of surface-plates, for instance—present other and at least equal difficulties. It then becomes necessary, as we have seen, to localise the action of the file, which of course would be impracticable in filing a flat surface with a flat file. Advantage is therefore taken of the convexity which to a greater or less degree is given to almost all files—partly to enable them to be used in this manner on large surfaces, but more especially on account of the great difficulty which exists in maintaining the original form during the processes of cutting and tempering. (The necessity for guarding against thus making either side concave is obvious; inasmuch as it could then never be used upon any flat surface.) To apply the pressure to a file of but slight convexity in such a manner that it shall be in contact with the work only in the part intended, will be found to require no inconsiderable skill, owing to the very small amount of guiding power which it possesses. Short

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strokes, with the application of local pressure by placing the fingers of the left hand on the back of the file just over the spot to be lowered, are often advantageous; but, in order to become a master of the art, the reader must submit to the tutorship of experience, for which verbal instructions are an utterly inadequate substitute. In whatever manner the file is held, it should be almost relieved from pressure during the backward stroke, in order that the teeth may not be blunted or broken by forcible contact with the work whilst they are placed unfavourably for offering resistance to it.

With regard to the height at which it is best to fix a piece of work which is to be filed up, that of the elbow of the operator will form an approximate guide; heavy work being somewhat lower with advantage, so that more of the weight of the body may be brought to bear upon it, and small work being more convenient when rather higher. In the latter case the height is generally regulated by that of tail- or bench-vice, into which a block of wood for supporting any work of irregular form can be so easily fixed. Thus, when it is required to reduce with the file the diameter of a wire or other small cylinder; a piece of wood being fixed in the vice, a notch is filed in it, and the wire, supported in this, is turned with the left hand through about a third of a circle during each stroke. When the file, as in this case, is held in the right hand only, the requisite pressure is frequently given by extending the forefinger along the back of it—as in holding a carving knife. But into the consideration of the treatment of curved surfaces, either convex or concave, we will not here enter, for they will present no insuperable obstacles to any one who has become sufficiently adept to produce a true flat surface.

Thin edges and narrow surfaces, which have a tendency to rip the teeth of a file when it is used across them, may be prevented from doing this by filing them either lengthwise or diagonally.

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In bringing any piece of work to a finished surface by using files of successive degrees of fineness, care should be taken entirely to remove the teeth-marks of the preceding file before passing on to a smoother one. The practice of drawing the file sideways along the work, which to some extent prevents its leaving the marks of its teeth, is not to be recommended; nor is that of giving it a rubbing motion, by which the surface becomes covered with curled scratches, instead of the parallel lines which result from a series of straight cuts given with the entire length of the file. When great smoothness is required a little oil may be used with a smooth file, which will diminish its tendency to become *pinny*, from the fibres (in the case of wrought-iron, &c.) being torn up and clogging its teeth. As good work cannot be produced with a file in this condition, a wire *file-brush* should be constantly at hand for clearing it when necessary, any very persistent particles being removed with the scriber, or some other metal point.

Glass plates, supported in suitable cast-iron frames, are sometimes used for surface plates. Their freedom from any tendency to rust is certainly a point in their favour.

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CHAPTER V.

ON FOOT-LATHES.

NOTHING definite is known as to the origin of the lathe. An old writer on the art of turning (Plumier)[1] attempts—but with very doubtful success—to show that King Solomon was acquainted with turned work. Amongst the sculptures of Nineveh there are various articles which have the appearance of having been turned; though these may have been produced with some rude apparatus, such as that still employed by native workmen in India, which can scarcely be dignified by the title of lathe.

The earliest drawings which show in any detail the construction of framed lathes seem to be two given in a work by Jaques Besson, printed in 1569.[2] The first published treatise on turning, written by an Englishman, Moxon,[3] appeared in 1683. This was shortly followed by the elaborate treatise of Plumier, which gives us a good insight into the state of the turner's art in France at that time; information which is well supplemented by the voluminous 'Encyclopédie,' which appeared in 1772.

The simplest lathes given in these works bear a strong resemblance to the old *Pole-Lathe*, which may still sometimes be met with. The diagram, Fig. 114, will explain its principle to those unfamiliar with it, and will render it intelligible how, without any metal-work except two dead centre-points, it is possible to construct a lathe which would be very serviceable in turning a bed-post. (The tool-rest is shown detached, on the left, in the diagram.)

[1] *L'Art de Tourner en Perfection.* Plumier: Lyon, 1701.

[2] *Theatrum Instrumentarum et Machinarum.* Besson: Leon, 1569.

[3] *Mechanick Exercises, or The Doctrine of Handyworks.* Moxon: London, 1677-83, 96.

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Such machines are not adapted for either accurate or speedy work,—the backward and forward motion obliging the turner to waste one half of his time whilst the spring-lath is raising the treadle, and is thereby producing a revolution in the wrong direction. Yet wonderful results were formerly obtained with them, not only in turning work of circular section, but also in oblique or 'swash' turning,

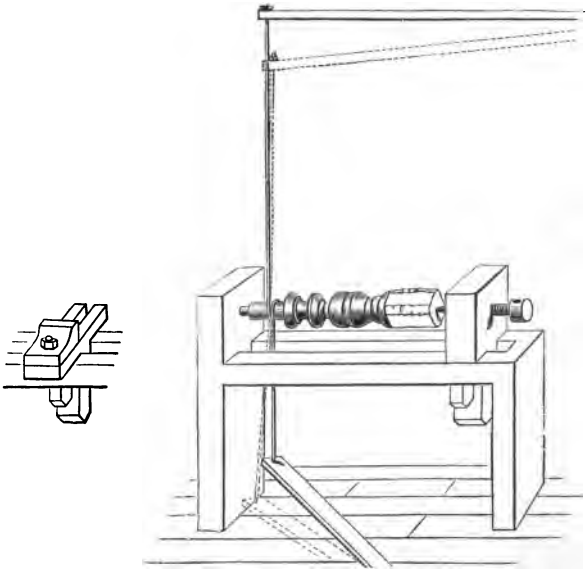

FIG. 114.—Pole-Lathe.

screw-cutting, rose or 'Guilloche' work, and oval turning, to which their adaptation seems to have been a favourite problem with the early lathe makers. An example of swash work, reduced from one of Besson's plates of 1569, is given in Fig. 115.

The change from the alternating motion to one of continuous rotation was a great step towards improving the

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efficiency of the lathe for almost every kind of turning. This seems to have been effected in the first instance by substituting for the lath and treadle a detached fly-wheel turned by an assistant, an endless band running from the margin of the wheel to some part of the work under treatment, which still revolved between dead centres, as in the pole-lathe. This system was certainly in use about the middle of the sixteenth century, and for heavy work detached fly-wheels are still sometimes employed by hand-turners. Lathes driven in this way do not, however, come within our present subject. Nor do the various forms of potter's-wheel, which, if they could be included, would enable the pedigree of the foot-lathe to be traced back to a period very much more remote than is otherwise possible.

The application to the lathe of the foot-wheel driven by

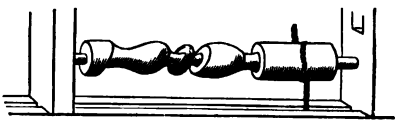

FIG. 115.—Swash Work.

a crank and treadle, which to us seems so simple and so obvious an arrangement, is comparatively recent, its use having apparently been exceptional rather than general even at the commencement of the present century; though when once its introduction had led to the essential parts of the foot-lathe being disposed in the manner now so familiar to us, there remained but little to be desired in the way of improving its general principle. Almost all subsequent improvements have either been improvements of construction rather than of principle, or they have aimed at extending its powers by means of supplementary apparatus used in conjunction with it.

Fig. 116 gives a good idea of a wood-turner's lathe at an early stage of its gradual development. It is evident that

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its construction involves the use of ironwork to a considerably greater extent than was necessary for a pole-lathe, but still the amount contained in it is but small. In converting his pole-lathe into a foot-lathe such as this, the turner of

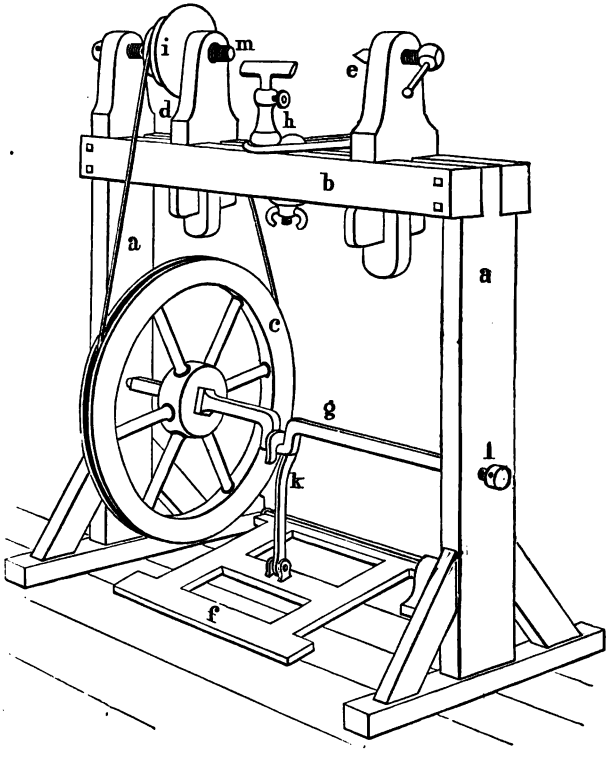

FIG. 116.—Old Wood-Turner's Lathe.

former days would have had to call in the aid of a blacksmith or a millwright to provide him with a cranked iron shaft (*g*), a hook (*k*), iron spokes, and perhaps also an iron boss, for the fly-wheel (*c*), an iron mandril (*m*), an iron tool-

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rest (*h*), if he had not previously possessed one, a few additional dead centre screws (*l*), but for little or nothing besides. The wooden standards (*a*, *a*,) the bed (*b*), and the fixed and moving headstocks (*d* and *e*) served him as before; the treadle (*f*) consisted of a wooden frame, and a built-up wooden ring formed the rim of the fly-wheel. The mandril pulley (*i*), and in some cases also the front bearing in which the mandril revolved, were of wood, though a thick iron plate bored out to fit the mandril and let into the headstock (*d*) was sometimes used, and must greatly have improved the steadiness and durability of the arrangement, which at best was a bad one.

In the construction of the mandril and headstocks, indeed, is to be found the chief point of superiority of the soft-wood turner's lathe of our own day. The framing often differs but little from that represented in the woodcut, and the wooden fly-wheel is sometimes retained by preference —owing chiefly to the facility with which it can be started and stopped—but the form and fitting of the mandril, which are first essentials to a lathe's satisfactory performance, show a very considerable advance.

Thus modified, such a lathe, which can be obtained at a very small cost, may suffice for turning the softer kinds of wood, for which approximate truth of outline only is required, more especially if any work which extends far from the mandril can be supported at its extremity by the back centre (*e*). But when harder materials, such as brass or iron, which demand a much higher degree of accuracy, have to be treated, or even when soft ones (owing to their being hollowed out or from other causes) cannot receive this additional support, so that their steadiness whilst revolving is dependent wholly upon the steadiness of the lathe generally and of the mandril in particular, then the unsuitability of timber for almost every part of a lathe makes itself felt.

Fig. 117 represents an ordinary *Mechanic's Foot-lathe* of modern construction. On comparing this with the old

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lathe (Fig. 116), it will be observed at once how very little woodwork now survives. The wooden bed has given place to one of cast iron (*b*), the standards (*a*, *a*,), the fly-wheel (*c*), the headstocks (*d* and *e*), are all now of cast iron, and even the framing of the treadle (*f*) is of wrought iron. Timber, in short, is entirely dispensed with, except for the foot-board of the treadle (*f*) and the back-board. (This last forms a sort of table behind the bed. Only the raised hinder edge of it

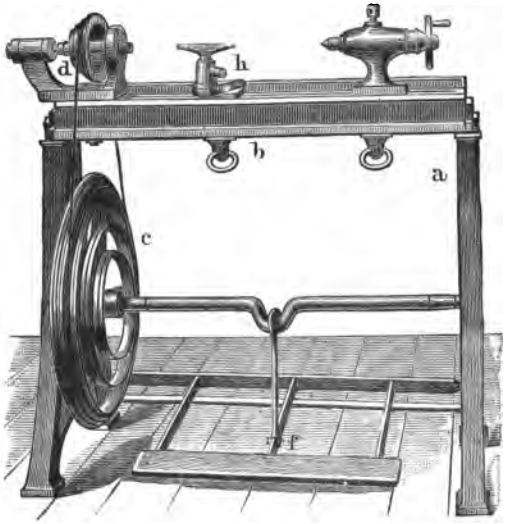

FIG. 117.—Mechanic's Foot-Lathe.

can be seen in the engraving.) Changes of construction have necessarily followed upon these changes of material, and the lathe designer, having become free to give to the several parts almost any form that seemed to him most suitable, which was not the case when he was bound by the exigencies of timber, considerable differences of detail have resulted.

In noticing one or two of these details let us bear in

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mind that a good foot-lathe should possess the following qualities:—

1st. Steadiness and absence of vibration throughout, but especially in the mandril, which must be incapable of any movement except one of free revolution round its axis.

2nd. Lightness in running.

3rd. Straightness and truth of bed, and perfect parallelism between it and the axis of the mandril, so that the back centre stands always accurately in line with the mandril.

4th. High finish in all working surfaces, and the use of materials for them which will insure durability.

It is also desirable that a lathe in which both hard and soft substances, or articles differing much in diameter, may have to be turned, should possess the means of varying the speed of the mandril to a greater extent than can be done by driving the fly-wheel faster or slower within the small limits of variation possible with the crank and treadle. This is generally effected by providing the edges of the fly-wheel and the pulley of the mandril with several grooves of different diameter, so that the lathe-band can run either in a large groove on the fly-wheel and a small one on the pulley, or the reverse. In the lathe represented in Fig. 117, the speed of the mandril can in this way be varied from 7 times to only $1\frac{2}{3}$ times that of the crank-shaft.

The general steadiness of a lathe depends much upon the form of the standards (*a*, *a*), which are usually provided with sufficient width of base to prevent motion in a direction transverse to the bed, but are not always sufficiently well connected with it at their summits to resist its tendency to vibration in the direction of its length.

Beds of foot-lathes generally now consist of two beams or 'cheeks' held a short distance apart by transverse pieces at their ends, the whole of these being cast in one. Whatever may be the form of its cross section, the bed must afford the means of keeping the fixed headstock (*d*) and the moving headstock or 'back poppet' (*e*) constantly in the

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line of the axis of the mandril. With the old wooden beds the only means of doing this was by carefully planing up the horizontal upper surfaces and the inner vertical faces of the two beams, each headstock being then provided with a vertical feather of a thickness exactly corresponding with the distance between the beams. The planing machine has rendered easy the adoption of the same plan with iron beds, for the cheeks of which the wide flat tops are often retained, though the planed portion of the vertical faces is much reduced in depth. Sometimes, however, both the horizontal and vertical faces are done away with, and others, inclined to one another at an angle of about 60°, are substituted for them, the upper edge of each cheek thus having its cross-section of the form of an inverted V. Corresponding V-shaped grooves are then made in the bases of the headstocks, which are thus kept in line without any vertical feather. The tool-rest is then furnished with a small sliding table with similar grooves on its under-side. A favourite form of bed is that of the lathe in Fig. 117, consisting of one flat and one V-shaped cheek, the flat one being in front, where the pressure is greatest. The table under the rest can be clearly seen in the engraving, and the section of the upper part of the bed is indicated in Fig. 157.

A single triangular bar frequently constitutes the bed of small lathes such as are used by watchmakers, the headstocks being placed as it were astride on its upper edge. This form, which is very effective in preventing lateral motion, was applied by Mr. Maudslay to large lathes as well as small ones, but for the former it has now been entirely abandoned, its resistance to torsion being clearly inferior to that of ordinary beds with double beams.

We now come to the most vitally important part of the turning-lathe, viz. the mandril, upon which both the lathe-maker and the lathe-purchaser should always bestow special attention, inasmuch as a badly designed or badly fitted

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mandril will certainly sooner or later be found unsatisfactory in its performance.

The left-hand portion of Fig. 118 represents a vertical section through the fixed headstock of a good foot-lathe for general turning. It will be observed that the mandril consists of a short round spindle or shaft, of which one end (the hinder end) is pointed, and the other is screwed, to receive chucks &c. for the attachment of the work. Immediately behind the screw is the front bearing, formed by turning the mandril truly cylindrical for about five sixths of the thickness of the headstock which carries it, the remaining sixth being

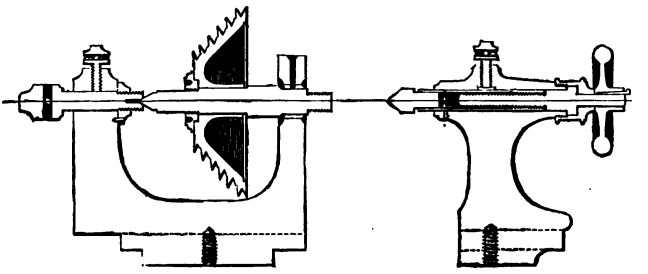

FIG. 118.—Sections of Fixed and Moving Headstocks of Foot-Lathe.

conical, so as to form a bevelled shoulder, which also is carefully faced. The entire mandril is now frequently made of steel, but when it is of wrought iron the bearing portion is case-hardened, so as diminish its tendency to wear. For a similar reason the headstock where the mandril passes through it is 'bushed' with steel. In this 'bush' the mandril is so carefully fitted that, although it is capable of revolving with perfect freedom, not the slightest tendency to 'shake' in a direction transverse to its axis can be detected.

The hinder end of the mandril, of which the point is invariably of steel, is carried by a steel (or steel-tipped) screw, of which the end is slightly hollowed out to receive

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it, a fine leading-hole running into the body of the screw for some little distance, so that when wear takes place the true centering of the mandril may still be maintained. This arrangement is sometimes reversed, the screw being pointed and the mandril recessed. In either case, by slightly tightening up the screw, compensation is obtained for any wearing away of the conical shoulder or its bush, a set-screw being added to hold the screw always perfectly firm, except when any such adjustment is required.

The necessity for employing such means as the above for always confining the revolving mandril to a truly circular path is obvious when we consider that every departure which it makes from such a path is reproduced in an increased degree upon the work attached to it, except when this is provided with some independent support, such as that of the back centre. A very small amount of slackness in the mandril induces the vibration or 'chattering' which, in certain kinds of work, is one of the greatest enemies of the turner. In some of the early lathes compensation for wear of the mandril was provided by giving to its front bearing a slightly tapered form throughout the thickness of the headstock; but it has then much tendency to become jammed, so that the cylindrical bearing and conical shoulder above described are a great improvement upon it.

The mandril pulley, with its conical form and its many grooves (of which the object has already been mentioned) can be clearly seen in the section (Fig. 118). Lathes intended for ornamental turning, and for some other purposes into which we cannot enter here, have the front face of the pulley graduated with scales of equal parts. To receive these graduations a brass plate is fixed to the face if the pulley be of wood—as it frequently used to be—or if it be of cast iron, as it now more frequently is. But the more highly finished modern lathes generally have the mandril pulley made wholly of gun metal.

The construction of a *Moving Headstock* or *Back Poppet*

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similar to that represented (at *e*) in Fig. 117 is shown in the right-hand portion of Fig. 118. Its chief use is to afford the additional support of a dead centre to any piece of work which would be unsteady, or would bring an undue strain upon the mandril if attached to it without such supplementary aid. The steel point, or 'back centre,' as it is called, is made to enter the revolving work to a short distance, thus giving the necessary support without materially adding to the friction. It is highly important that the back centre should be always exactly in the line of the axis of the mandril, whilst at the same time the distance between it and the headstock must admit of ready and rapid adjustment. The poppet is therefore made movable along the bed, the form of which confines its motion to the proper line, as already explained, a screw, working in the tapped hole which appears in the section, enabling it to be securely clamped in any position along the line.

After the poppet has thus been fixed close to the end of the work the back centre can be adjusted by turning its hand-wheel, which works the sliding cylinder by which it is carried. An examination of the section in Fig. 118 will explain the reason of its movement. The spindle upon which the hand-wheel is keyed is screwed for about half its length into the sliding cylinder, this being made hollow in order to receive it. But a large shoulder, which is kept up to the back of the poppet-head by a cap, prevents the spindle from changing its own position ; and a pin, running in a groove upon its under-side, resists any inclination on the part of the sliding cylinder to revolve with the spindle. When, therefore, the hand-wheel is turned, the cylinder is made to slide, towards the mandril when the upper part of the wheel is moved to the right, and away from it when to the left, the screw upon the spindle being made left-handed with this intention. The back-centre having thus been satisfactorily adjusted, the sliding cylinder can be clamped by the set-screw above it. It is evident that the back-centre

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can be always truly in line with the mandril only if the cylinder which carries is also in line, so that the correct boring of the poppet in the first instance is a matter of great importance.

In drilling metal, &c., with a drill attached to the mandril, a circular plate, flat in front, and having at its back a boss fitting into the end of the sliding cylinder, may be advantageously substituted for the steel point.

The *Tool-Rest* (*h*, Fig. 117) has already been alluded to. It is capable of free movement horizontally in any direction on the lathe bed, but can be instantly clamped at any point by means of a bolt which passes downwards to the handle below the bed, the bolt-head fitting loosely in a dove-tailed groove on the under side of the stand which carries the T-piece upon which the tool is rested. A set-screw, which appears in the engraving, enables the T to be fixed at any desired height. One or two extra T-pieces are generally supplied with a foot lathe, additional length of head being advantageous in turning long cylindrical work, and a broad flat head being necessary for some kinds of metal turning.

The size of the work which can be turned in a lathe is limited by the height of the axis of the mandril above the bed, twice this height being the greatest diameter admissible. In order to judge of the capabilities of any particular lathe, we must know this height, and also the length of the bed, which, after deducting the portions of it occupied by the headstock and back poppet, determines the length of work which can be treated. Thus the lathe in the figure (Fig. 117) would be described as a 5-inch lathe, 3 feet 6 inches bed, and it could take in work 10 inches in diameter or 2 feet long.

Lathe-bands, by which the power is transmitted from the fly-wheel to the mandril, are best made from a single strand of catgut, though cord, gutta-percha, and other substances are occasionally used. Whatever the material, the two ends should be securely joined together without any sudden

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increase in the diameter of the band. In the case of gut this is usually effected by screwing the ends into a pair of small steel sockets, one of which terminates in a hook and the other in an eye, as in Fig. 119, and this has the advantage of enabling them to be readily disconnected when a

FIG. 119.—Hook and Eye for Lathe Band.

different length of band has to be substituted—as for the slow speed in the lathe represented in Fig. 117.

When no such change is required, as in lathes for soft-wood turning only, the arrangement shown in the diagram (Fig. 120) possesses advantages. The mandril pulley and fly-wheel have then each only a single groove, the band taking a complete turn round the pulley, so that it has much less tendency to slip, and its tightness can therefore be much reduced. Vertically over the mandril is a hinged or pivoted frame, carrying a freely revolving sheave over which the band passes, and by which, through the action of a weight increased or diminished at pleasure, its tension is regulated. It will be observed that whether the tension is great or small it puts no side strain upon the mandril, nor does its amount vary with every change in the degree of moisture in the atmosphere, which is a source of constant trouble with bands arranged in the ordinary way.

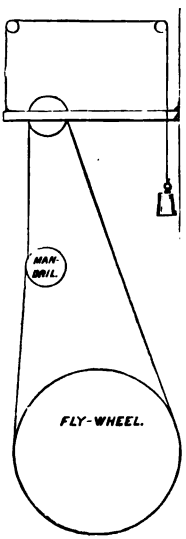

FIG. 120.—Lathe band with tightening pulley.

The first step in a turner's operations ordinarily consists in attaching his material to the mandril in such a manner that it may share its

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revolution. For this purpose he provides himself with an assortment of *chucks*, each of which, being fitted to the mandril by means of the coarse-threaded screw at its extremity, can be readily attached or removed from it. Commencing with those which generally accompany a wood-lathe, we shall find that the one which shows the smallest advance upon the old system of fixing between two dead centres (as in Fig. 114) is the *fork-chuck* (Fig. 121). The fork being driven a small distance into one end of a piece of wood, the other end is supported by the back-centre. For work which requires to be turned on the outside only, without being 'hollowed' at all, this method of

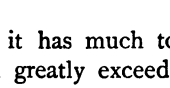

FIG. 121.—Fork-Chuck (½).

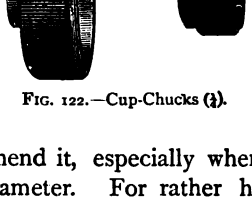

FIG. 122.—Cup-Chucks (½).

fixing it has much to recommend it, especially when the length greatly exceeds the diameter. For rather harder materials a smaller kind of fork is often used—the *cross kerf*—of which the prongs are arranged thus (+), enabling work of much smaller diameter to be turned up to the end without fear of their coming into contact with the edge of the tool. In either case the fork is fitted, either movably or permanently, into its chuck, which may be either of wrought or cast iron, brass, or gun-metal—the latter being generally preferred, though it seems to possess but little advantage over malleable cast iron, either for this or for any of the ordinary foot-lathe chucks.

From two to six *cup-chucks* (Fig. 122) are usually supplied, and the turner is apt to supplement these with many others which he makes for himself from pieces of hard wood 'tapped'

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to fit the mandril screw. They are, above all others, in constant requisition. For when once a piece of work is securely 'chucked' by fitting and driving it into a cup-chuck—and the knack of doing this with speed and certainty is one which it is most important for a turner to acquire—the support of the back centre becomes no longer necessary, so that the work can be drilled or hollowed out, or its end face can be turned in any desired manner, provided, at least, that its length does not greatly exceed its diameter.

Wooden cup-chucks often have additional elasticity given to them by slitting them for a considerable portion of their length with a series of longitudinal saw-cuts, in the manner shown in Fig. 123. Such chucks are used in turning billiard balls, and for many similar purposes, and are known as *Spring Chucks*. They hold with a very firm but delicate grip, when the diameter of the cup is just sufficiently smaller than that of the work to oblige the saw cuts to spring open slightly in order to admit the work, and the grip can be further increased, if required, by forcing a ring over the slightly tapered exterior of the chuck.

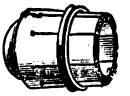

FIG. 123.
Spring Chuck.

Fig. 124 represents a *Screw Chuck* for holding pieces of work of small thickness, which may be of as large diameter as the lathe can take—such as wooden discs cut 'plankways' of the grain. For chucking such things, however, a turner often prefers to employ a simple piece of hard wood screwed upon the mandril and glued to the back of his work, which is thus saved from the disfigurement of the hole which the screw-chuck leaves behind it.

FIG. 124
Screw Chuck.

Two chucks for the attachment of metal-work will probably complete the list of apparatus included by the maker with a lathe such as we have been describing. These are the arrangements known as the *Dog and Driver*, or *Driver and Carrier*, and the *Face Plate*.

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The principle of the driver and carrier consists in supporting the work upon two steel points by means of a small centre hole at each of its ends, one point being attached to the mandril, the other to the poppet or back centre. It is thus rigidly supported, and is incapable of

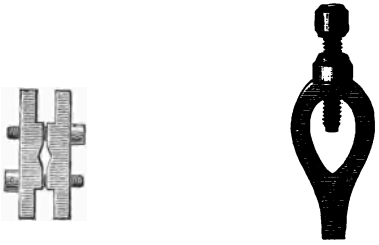

FIG. 125.—Carriers (¼).

any motion except that of revolution. In order to cause it to revolve with the mandril, a dog or carrier is attached to the end of it which lies towards the left hand of the workman, and a driver is so fixed to the mandril as to move with it. The forms of *Carriers* vary with the shape of the work

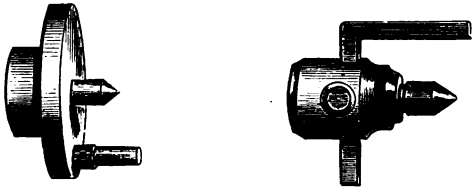

FIG. 126.—Drivers (¼).

to which they are to be applied, those represented in Fig. 125 being amongst the most useful for circular and other ordinary sections. Fig. 126 shows the *Drivers* which are most frequently used in foot-lathes. The facility with which this system lends itself to work of the most varied shapes and sizes,—provided that its exterior only is to be turned,—

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together with the advantage which it presents in enabling it at any time to be again chucked concentrically, combine to make it of very general application. The rigidity with which the work is thus supported—which is a very necessary quality when hard and unyielding materials are under treatment—is also much in its favour.

Face plates are as largely employed for holding metal-work which has to be treated in the lathe without having the support of the back centre as drivers and carriers are for such as can be so supported. Those of the small sizes used with foot-lathes consist—as may be seen in Fig. 127—merely of a strong cast-iron plate, somewhat increased in thickness at its centre, where it is tapped to fit the mandril screw. The face, which is turned true and flat, is perforated with numerous holes or slots, or with a combination of the two. To this face the work is secured by means of bolts passed through the plate and through holes in the work itself when such exist in suitable positions, or, when they do not, by clipping it with hook-bolts or clamps, or in any other way that suits the particular case. Several forms of clamps are given in Fig. 128, the method of applying them being sufficiently

FIG. 127.—Face Plate.

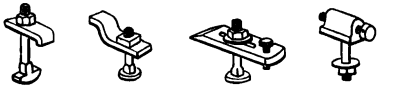

FIG. 128.—Clamps for Face Plate.

obvious. The one on the left hand is shown with a T-headed bolt, which is convenient, as it can be passed through a slotted face-plate without removing the nut. That on the right hand enables objects to be secured upon the face-plates even when they have no projecting flanges which can be clipped, four, or at least three, of these being, of course, used simultaneously.

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These also give great facilities for centering correctly any piece of metal-work, which it is generally of much greater importance to be able to do when dealing with hard materials than with soft ones.

Amongst the chucks for metal which are occasionally used with the foot-lathe, though their duties are for the most part amongst the heavier lathes which we shall notice presently, the three following should be mentioned. The *Four-jaw Chuck* (Fig. 129), which is, in fact, a face-plate with four permanently attached jaws, each of which can be moved independently, in a radial direction, by means of a screw behind it recessed into the back of the plate. Their pressure can be either inwards or outwards, so that work can be held by them either externally or internally, as most

FIG. 129.
Four-jaw Chuck.

FIG. 130.
Bell Chuck.

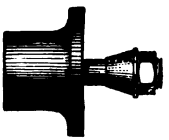

FIG. 131.
Cone Chuck.

convenient. With this chuck, and also with the *Bell Chuck* (Fig. 130) which admits articles of small diameter only, but holds them with great firmness, true centering is only a question of suitable adjustment of the screws.

The *Cone Chuck* (Fig. 131), on the other hand, is a self-centering chuck, though one of somewhat limited application. It is chiefly useful for chucking any flat piece of work (such as a circular disc) which has a central hole, but the hole must be of sufficient, and not of too great size for the cone, which slides upon the central pin of the chuck, to take a bearing in it.

A common method of chucking such things as discs or rings is merely to drive them tightly upon a mandril or

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arbor, either parallel or tapered, the arbor itself being then chucked with the driver and carrier in the manner described above. But with a taper arbor, unless the hole in the work is similarly tapered, the fit cannot be otherwise than imperfect. *Expanding Mandrils*, such as Fig. 132, enable a tight grip to be obtained with a parallel-sided hole of any diameter within the range for which the mandril is made. The

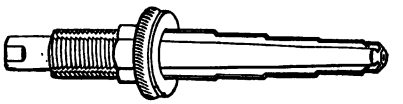

FIG. 132.—Expanding Mandril.

action of the three sliding feathers by which this is effected will be readily understood from the engraving.

The great saving of time which results from the employment of self-centering apparatus in the lathe has of late brought chucks upon this plan into very extensive use. A great variety of American (or so-called American) chucks are now to be met with, the work being held in them by

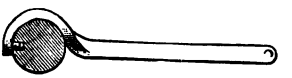

FIG. 133.—Chuck Wrench.

three or four jaws which can be moved simultaneously in a radial direction. The device is by no means new, chucks on this principle having been made in the workshop of the late Mr. Holtzapffel many years before American ones were heard of.

A *Scroll Chuck* of this kind with three 'stepped' jaws is represented in Fig. 134, together with a section through the centre which will explain its action. The body of the chuck is formed of three pieces, marked A, B, and C, which, however, when once put together, form to all intents and purposes but one piece. Inclosed between A and B is a

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ring, D, which can revolve independently. In the face of the chuck are three radial grooves, each of which has two feathers projecting from its sides into the body of the groove. Sliding freely along these grooves and feathers are the three jaws. On the face of the ring (D) a spiral of about $3\frac{1}{2}$ revolutions is cut, of such width and depth that its section resembles that of a square-threaded screw. Counterparts of the spiral are formed on the internal edge of each of the

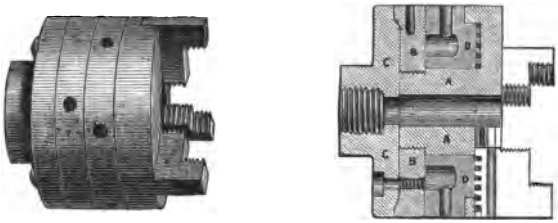

FIG. 134.—Scroll Chuck, with section through Centre.

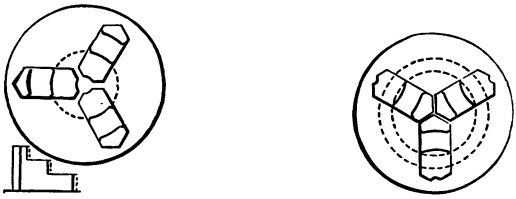

FIG. 135.—Reversible Jaws of Self-centering Chuck.

jaws, which, when in position, are in contact with the face of the ring D. Consequently, by causing this ring to revolve while the body of the chuck is at rest, the three jaws are all made to advance or to recede from the centre to an equal extent. This is readily effected by introducing two pins, or—what is better—two chuck-wrenches, of the form shown in Fig. 133, into the holes made for that purpose in the circumferences of B and D.

Scroll chucks, however, are now generally made lighter

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and less cumbrous than the above, and the work is brought much nearer the mandril, to which it should always be kept as close as possible. In some patterns of self-centering or 'universal' chucks, as they are sometimes called, means are also provided for moving each jaw independently when desired, and the jaws are made either reversible, as in Fig. 135, for chucking articles internally, or altogether removable, so that they can be changed for others more suited to any particular piece of work.

Small self-centering chucks are now very much used for chucking twist drills and cylindrical work of small diameter. One such *Drill Chuck* is represented in Fig. 136, but many other varieties are to be met with. When made with sufficient correctness to insure the jaws running true in all

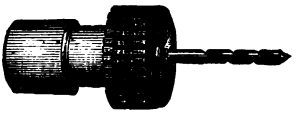

FIG. 136.—Drill Chuck (½).

positions, and when once truly fitted to the mandril (an operation by no means free from difficulty), a drill chuck is one of the most serviceable additions which can be made to the accessories of a foot-lathe.

Before self-centering chucks came into general use, metal spring chucks, on the same principle as the wood spring chucks above described, or *Die Chucks*, with various forms of adjustable dies, were employed for holding drills, wires, &c., in the lathe. The chief disadvantage of spring chucks for the purpose is that each is adapted only to one particular diameter, to which the shank of each drill, or a portion of each piece of work to be chucked in it, must therefore be reduced; and die chucks—such, at least, as have a pair of dies working independently of each other—entail trouble in centering, and have no means of adjusting the work except in one direction. On the other hand, they

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can take in articles which chucks with three jaws cannot—such as those of which the cross-section is rectangular.

The *Boring Collar* (Fig. 137) is occasionally of great service in enabling a piece of work to be bored in the lathe, even though its length or other causes may require that it should have support resembling that of the back centre, which clearly cannot be used in such cases. It consists of a thick vertical plate containing a series of countersunk holes of different sizes, which can be clamped at any part of

FIG. 137.—Boring Collar ($\frac{1}{8}$).

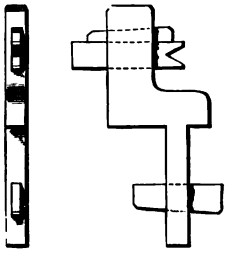

FIG. 138.—Wooden Back-stay.

the lathe bed. When in use, whichever hole is of suitable size for the extremity of the work to enter, but not to pass through it, is brought to the top, in which position the centre of the hole is in the line of the axis of the mandril. The boring tool is then applied from the opposite side of the plate.

The cast-iron support which carries the boring collar is also sometimes fitted with an adjustable *Back-stay*, for the purpose of steadying any very long or slender articles

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whilst being turned. A wood-turner's substitute for it, which arrives at the same result by much less costly means, is shown in Fig. 138 ; and in Fig. 139 is an independent Back-stay sufficiently rigid for metal work.

The tools of the professional wood-turner are apt to be few in number and simple in kind. For soft wood two or three *Chisels* and *Gouges* of different sizes, and a *Parting tool*, meet most of his requirements as far as outside turning is concerned, whilst for inside work he supplements these with some form of *Side tool* for smoothing the hollowed portions, which he easily and quickly roughs out with his gouge. Some soft-wood turning tools are represented in Figs. 140 to 144. The oblique edges of the chisels (Fig. 140), which are ground from both sides, and the almost pointed shape of the gouges (Fig. 141) should be noticed, as in these respects —as also in acuteness of the angle to which they are ground—they differ greatly from the joiners' tools in Chapter II. The length of their handles is also characteristic. The *Parting tool*, or 'scriever' for soft wood (Fig. 142), is distinguishable by the V-shaped groove in its upper surface, which converts what in its hard-wood representative is a mere scraping edge into a pair of lancet-like points, capable of making a perfectly clean cut across the slightly cohering fibres of the wood. Its action is thus precisely analogous to that of a cross-cut saw.

FIG. 139.—Metal Back-stay.

Hook tools (Fig. 144) are used for undercutting or hollowing work which cannot be reached with a gouge, owing either to the great depth of the hollow, or to other causes. Their stems, and also those of the *Side tools* (Fig. 144), are sometimes cranked, in the manner shown in the engraving. The object of this is to obtain greater purchase for resisting the tendency to turn over whilst cutting, which is considerable in 'greedy' tools of this kind.

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For the harder kinds of wood and other materials of medium hardness, the hand-turner often employs chisels and gouges resembling these, but ground to a less acute angle, so as to have thicker and stronger edges. Scraping

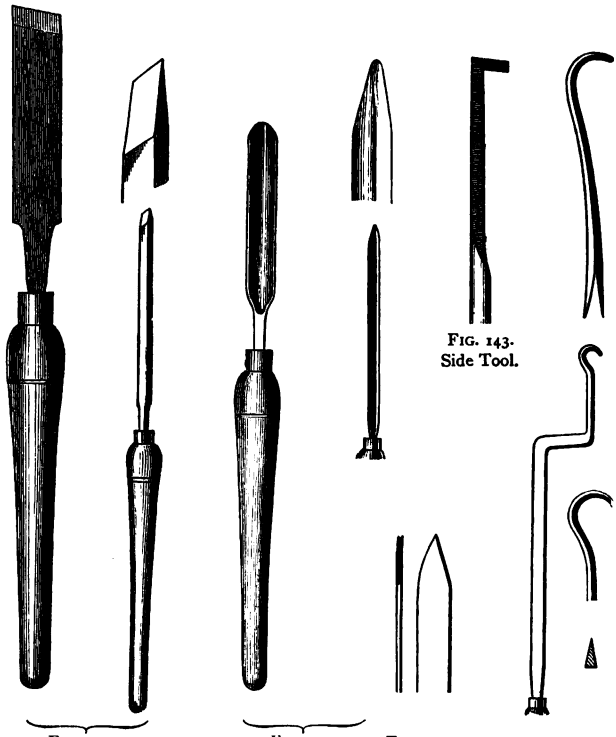

FIG. 143. Side Tool.

FIG. 140. Chisels.

FIG. 141. Gouges.

FIG. 142. Parting Tool.

FIG. 144. Hook Tools.

TURNING TOOLS FOR SOFT WOOD.

tools, however, supersede them to a great extent even for hard wood, and almost entirely for still harder substances, such as ivory, brass, &c. The *Round tool* (Fig. 145) and *Side tool* (Fig. 146) may be taken as types of such scraping

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tools, their shapes and the angles or 'thickness' of their edges being varied as required. *Inside Parting tools* (Fig. 148) are used in the manner implied by their name, and are often of service for removing in a single piece from hollowed work a considerable portion of material which must otherwise have been wasted. Besides these we can only here mention the *Diamond-pointed Graver* (Fig. 149), a service-

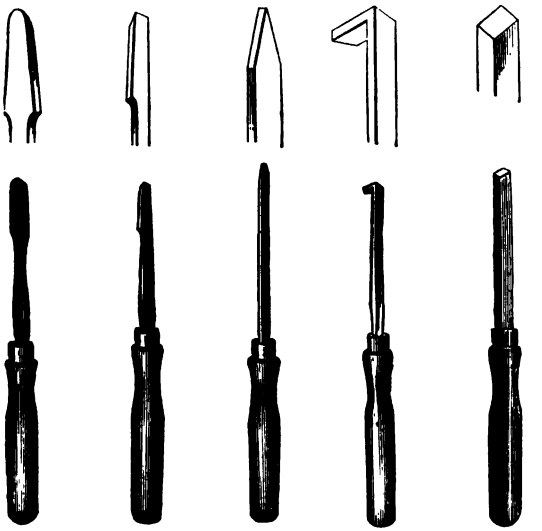

FIG. 145. Round Tool. FIG. 146. Side Tool. FIG. 147. Parting Tool. FIG. 148. Inside Parting Tool. FIG. 149. Diamond-pointed Graver.

TURNING TOOLS FOR HARD WOOD, BRASS, &c.

able tool which, according to the position in which it is held, forms either a scraping or a paring tool, and acts efficiently either upon boxwood—that perfection of material for hand-turning—or upon metals as refractory and unpleasant as copper and wrought iron.

For turning wrought-iron and steel tools which act by scraping only are not adapted. Their edges and the

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inclination at which they are held should be such as to insure a cutting action almost resembling that of a soft-wood paring chisel. But for these stubborn materials hand tools are now but little employed, except for work of small diameter, the great steadiness which is essential to making an efficient cut being difficult of attainment when the tool

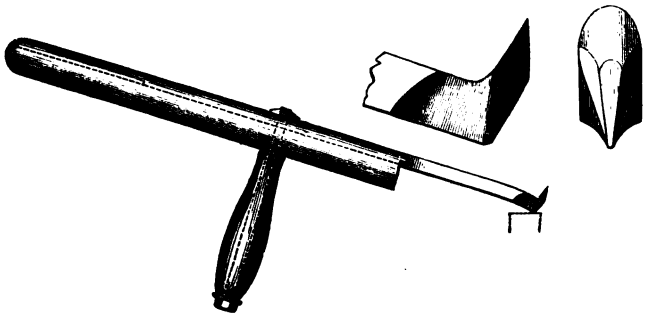

FIG. 150.—Tool-holder and Heel Tool for turning Wrought Iron and Soft Steel.

is held in the hand, and easily attainable with a slide-rest. Consequently the *Heel tools*, which in former days were the turner's only means of successfully attacking such substances, have now fallen greatly into disuse. In using these tools—forms of which are shown in Figs. 150 and 151—

FIG. 151.—Tools for turning Cast-Iron.

the 'heel' is supported by the wide and flat-topped rest already alluded to, the pressure produced by the cut being thus transferred directly to the rest-holder and lathe-bed, and causing little or no strain upon the hands of the workman. But the necessity for having the tool completely under control, and the small amount of motion to be given

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to it for determining the depth of its cut, obliges it to be securely fixed in some long and powerful handle. It is therefore used with a *Tool-holder*, such as that which appears in the engraving, being laid in a groove on its upper surface and there held by an eye-bolt which passes through the handle, and which can be tightened by a nut at the lower end of it. The tool-holder is of sufficient length to pass under the shoulder of the operator, its upper portion being firmly grasped by his left hand, and the handle held in his right. The tendency of heel-tools to catch in the work can thus be resisted, though their use requires caution, especially if used with power lathes, one fatal accident in turning up a wrought-iron crank through the workman being thrown completely over the lathe having come to the author's knowledge.

It must, of course, not be supposed that the tools shown in the foregoing figures are the only kinds employed for the several purposes mentioned. They have been chosen merely as every-day examples, and they are not necessarily the best adapted to any particular case. A handy turner, indeed, will sometimes altogether alter the form of a tool that it may the better serve his purpose, or he will extemporise one for himself from an old smooth file or other suitable piece of

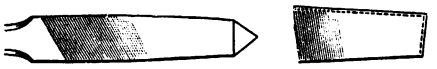

FIG. 152.—Home-made Turning Tools.

steel. A side tool, for instance, can be readily made by grinding down a worn-out flat file in the manner shown in Fig. 152, or a 3-square file can be converted into a pointed tool capable of doing quite as good service as a diamond-pointed graver.

For such purposes, as well as for properly maintaining the edges of all his cutting-tools, a good grindstone ready for use at any moment is a first essential to the turner, good

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results being almost incompatible with the use of blunt tools in this as in other crafts. With soft materials especially their bad effects cannot be thoroughly removed by any subsequent treatment—with glass-paper, for example—so that the first lesson which should be learnt by a beginner is the art of using his grindstone and oilstone with speed and effect.

The edges of turning-tools intended for soft wood should be ground to an angle of from 20° to 30°; those for hard wood, to from 40° to 80°; whilst those which are to be used for brass may even exceed this latter angle, having sometimes a thickness of as much as 90°. In grinding turners' gouges, of which the edges possess the double curvature which gives them the circular or elliptical outline seen in the engraving, Fig. 141, the wrist motion mentioned in connection with the grinding of carpenters' gouges is required, and, in addition to it, constant change in the height at which the tool is applied to the stone. In the round-nose and such tools, of which the edges are curved in this one direction only, a similar change of position upon the stone is also necessary; but in their case it must not be accompanied by any revolution about the axis of the tool.

Substances of which the hardness is equal or superior to that of tempered steel cannot, of course, be worked with steel tools, either in the lathe or out of it, so that in their case the turner is compelled to seek some still harder material. Nothing that we are acquainted with exceeds the diamond in hardness, and when mounted as a hand-tool, or, still better, as a slide-rest tool, it can sometimes be used with good effect upon mineral substances against which steel is powerless. But for turning hardened steel itself, it is best employed in the indirect manner which will be pointed out in a future chapter in connection with emery grinding.

Boring Bits and Drills are frequently employed by turners in a reverse way to that in which they are used for drilling, the work being made to revolve instead of the drill. The *Spoon Bit* (Fig. 58) often serves for boring soft

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materials in this way, and several of the drills in Fig. 74, for boring hard ones. Two *Boring-tools*, of which the use is confined to the lathe, are represented in Fig. 153. The old form of *Drill* (*g*)—to which Plumier gives the descriptive name of 'langue de serpent'—is not suitable for either very hard or very soft materials. The *Half-round Bit* (*h*) is for

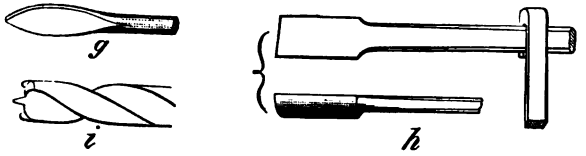

FIG. 153.—Boring Tools.

hard substances, which it is capable of boring truly and smoothly. At the opposite end to that shown in the engraving it has a centre hole, by means of which it is supported on the back centre and driven forward by the poppet screw, a spanner or clip preventing it from revolving. Its chief use, however, is to give a smooth finishing cut to a

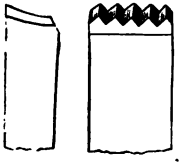

FIG. 154.—Outside Screw Tool.

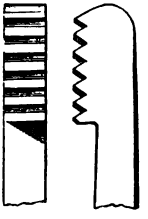

FIG. 155.—Inside Screw Tool.

hole already drilled in any piece of metal work, and it is well adapted for correcting the irregularities which result from using drills which do not themselves possess sufficient means of guidance; but it seems preferable to avoid these errors in the first instance by employing twist drills or others which are free from this great defect. A self-guiding centre-bit, consisting merely of a drill of this kind, provided

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with a spur and lips, which cuts a straight and clean hole through soft wood in any direction of the grain, and which forms an excellent boring-tool for use in the lathe, is also shown in the engraving.

The production of screw-threads by means of *Chasing tools* is one of the prettiest operations of the hand-turner's art. The cutting portions of a pair of such 'chasing' or 'screw' tools are represented in Figs. 154 and 155, the one being used for external, and the other for internal or 'female,' screws. Tools with coarse threads have been chosen for these illustrations for the sake of clearness, but fine ones are principally used. In chasing a screw-thread, a perfectly uniform motion parallel to the axis of the work must be given to the tool, the speed being such as to make it advance one thread during each revolution of the mandril. As might be expected, the operation requires considerable practice, especially in cutting coarse threads, for which the motion of the tool is considerable—error in the speed imparted to it resulting either in uneven or 'drunken' screws, or in double threads. But a good workman can thus produce with ease and certainty screws of the greatest cleanness and delicacy, and—the pressure required being very slight—they can be cut by this method on the thinnest and most fragile materials, which would be quite unable to resist the more violent treatment to which they would be subjected in the screw-cutting processes previously mentioned. This system is used to a very great extent by opticians for the brass fittings of telescopes, microscopes, &c., the thickness of the brass 'triblet' tubes employed frequently exceeding only to a very small extent the depth of the screw-thread which is cut upon them.

Foot-lathes are occasionally provided with mechanical means for screw-cutting, but this always entails some sacrifice of lightness in running. The *Traversing Mandril* is an old expedient for that purpose. The 'traverse' is obtained by making the mandril parallel throughout both its bear-

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ings, and for some distance behind each, and providing some portion of it with an external screw similar in pitch to the one which is to be cut. This screw, being made to engage with a corresponding nut (or portion of a nut) attached to the headstock, causes the mandril at each revolution to move endways through a space equal to the distance between the threads. Consequently a pointed tool held perfectly still in contact with the work will trace out upon it a similar screw-thread.

With a traversing-mandril the back centre cannot be used, so that the threads of long screws or any articles for which the support of the mandril is insufficient cannot easily be cut in this way. Their production, and indeed all turning of metal work of which either the length or the diameter is considerable, lies rather beyond the province of foot-lathes. When it is necessary to employ them for such purposes, they require to be provided with self-acting gear resembling that of screw-cutting power-lathes, particulars of which will be found in the next chapter.

The immense advantage which would be gained by having a rigid support for a turning-tool, provided that at the same time a perfectly controllable movement in any desired direction could be given to it, will now be self-evident to the reader. It is therefore unnecessary to dwell upon the value of the *Sliding Rest*, which fulfils these requirements. Its introduction has done more towards extending the capabilities of the turning-lathe than have all other improvements put together.

Before entering into the details of its construction, we should mention that the term 'slide' is here used to denote two portions of a piece of mechanism, so connected together that movement can take place between them in one definite direction, but in no other. Just as we saw that an ordinary lathe-mandril must be able to revolve freely, but in all other respects must be immovable, so the two parts of a slide must be incapable of any independent motion except

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the particular one for which they are constructed. This result can be obtained by jointing them together in various ways. The 'dovetailed' joint, which appears twice in Fig. 156, is one of the simplest for the purpose, but several other forms of joint will be observed amongst our examples of machine tools, many of which depend for their very existence upon the practical application of the principle of the slide.

A well-made slide must work with equal freedom at all parts of its traverse, without exhibiting any looseness or 'shake.' These conditions can be completely fulfilled only

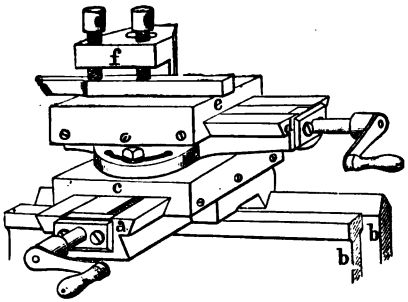

FIG. 156.—Side-Rest.

when the sliding surfaces are perfectly similar and parallel: so that although the principle is simplicity itself, the operation of fitting a slide with sufficient accuracy is by no means an easy one. It in fact resolves itself, in the case of ordinary slides, into the production of four pairs of parallel and truly plane surfaces, an operation of which the difficulty was almost insuperably great before the introduction of the scraping process described in Chapter IV.

Fig. 156 represents a simple *Slide-Rest*, adapted for use with a foot-lathe. Clamped upon the lathe-bed *b*, *b*, is the base-plate *a*, which, with the sliding-plate *c*, forms the lower slide. Similarly *d* and *e* form the upper or cross-slide, on

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the top of which is the tool-holder *f*. Each slide is provided with a horizontal driving-screw with a handle attached to it, by turning which, motion can be imparted to the tool in a direction either parallel or transverse to the lathe-bed. And by combining these movements, or by altering the angle at which the upper slide is fixed upon the lower one (which a central pin and two bolts working in circular slots provide the means of doing), the slide-rest can also be used for turning conical and other surfaces.

It is important that the tool used with a slide-rest should be securely clipped, so that it may share to the full extent the steadiness of the rest itself. It must also be capable of being fixed parallel with either the upper or the lower slide, or at any inclination to them. The fixed tool-holders formerly in use did not admit of this last desideratum, and to obviate this and other inconveniences connected with them, Professor Willis, in 1842, devised his revolving tool-holder, which is similar in principle to the one in Fig. 156. This, when the set-screws which clip the tool are slackened, is free to revolve round the bolt which holds it down to the upper slide.

FIG. 157.
Circular Tool-Holder.

Another tool-holder, rather more compact in appearance, which affords similar facilities for fixing the tool at any angle, and effects it by means of a single screw, is shown in Fig. 157. When it is not exerting pressure upon the tool, the slotted cylinder can be turned round on its axis. Its inability to hold any tool which cannot be passed through the slot is its chief disadvantage. But none of these tool-holders are now much employed, except in the case of the small slide-rests, of which the use is confined to the foot-lathe. In those of larger size, the only permanent provision for holding the tool is generally the introduction of four bolts into the upper portion of the cross-slide. These are

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fixed with their heads downwards, and the tool is secured by being placed beneath two short perforated bars, which are slipped over the ends of the bolts, nuts being then screwed down upon them. The arrangement may be observed in the engraving of the duplex lathe (Fig. 182), and elsewhere in the next chapter, two only of the holding-down bolts being in use, and the opposite ends of the bars being supported by a short packing piece of the same height as the tool.

Some examples of the slide-rest tools adapted for use with foot-lathes are given in Fig. 158, the uppermost of

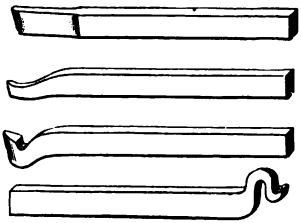

FIG. 158.—Slide-Rest Tools for Foot-Lathes.

them being known as a 'round nose,' and the others as a 'square nose,' a 'hook tool,' and a 'spring tool,' respectively. The first of these is shown also in position on the slide-rest, Fig. 156. Such tools for the most part differ in respect of size only from those with which heavy work is treated in power-lathes,—some of which will be found amongst the engravings in the next chapter,—the former being rarely made from larger steel than half-inch square, and one-inch square being the smallest ordinary size for the latter.

Considerable economy in tool steel can be effected by employing loose cutters and *Cutter Holders*, such as Fig. 159, the holder being there made of inferior steel, or even of iron. The system was long ago advocated by the late Mr. Babbage, on this score, and also on account of the much greater facility with which loose cutters can be sharpened.

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Thus, the ordinary diamond-pointed hook tool in Fig. 158 must be carefully forged and tempered to begin with, and, when blunt, must be ground at the top and on its two sides. A similar tool can be made by fixing in an appropriate cutter-holder a short piece of steel of triangular section, which can be sharpened by grinding its upper face only. The necessity for adjusting the height of the rest, as the tool gets worn away in sharpening, is also dispensed with when holders with loose cutters are substituted for the usual hook tools. Several patterns besides that shown in Fig. 159 are now made, some of which will be found in Chapter VI.

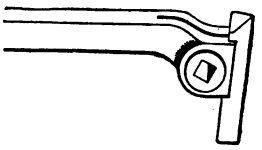

FIG. 159.—Cutter-Holder.

Two patterns of *Turners' Callipers* are shown in Fig. 160, those on the left hand having points equidistant from the

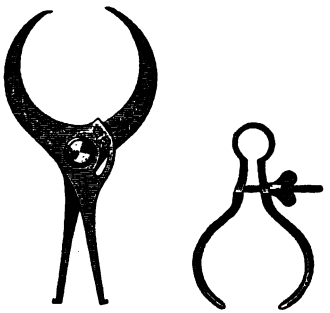

FIG. 160.—Turners' Callipers.

centre at both ends of their legs, so that exact correspondence between an 'outside' diameter measured with the one, and an inside diameter checked by the other, can easily be obtained.

The *Centering Square* (Fig. 161) is a simple expedient for finding the centre of any circular piece of wood, or other

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material, of which the radius does not exceed the length of the blade. Bringing the V-shaped stock up to the circumference in any two positions, and passing a pencil or scriber along the blade, the point of intersection of the lines so drawn shows at once the centre of the circle. In the case

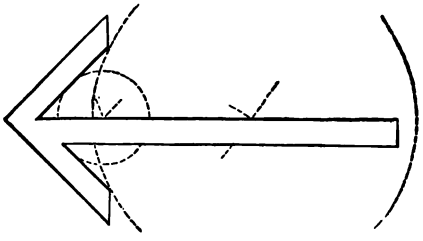

FIG. 161.—Centering Square.

of circular work of small diameter the centre can be even more readily found by means of the *Centering Punch* (Fig. 162), which is merely a pointed steel punch with parallel sides, sliding freely in the stem of an inverted funnel, or centering cone. To whatever distance the circular end of the work may enter this cone, the point of the punch will be always at its centre, which spot can be marked by giving the top of the punch a light blow with a hammer. This simple contrivance does not seem to have met with very general acceptance, though without the cone the pointed centre punch is to be met with in every workshop in which metal-turning or drilling is carried on.

FIG. 162. Centering Punch.

To attempt to describe the various accessory and occasional apparatus used with foot-lathes would lead us far beyond our limits, but we may briefly notice in conclusion a few of those which frequently provide the amateur with innocent recreation,

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though they are not often to be found in the shop of the professional turner. For further information than we can now give respecting them the reader must refer to the various treatises specially devoted to the subject, to one of which[1] we are indebted for Figs. 139, 165, and several of the succeeding engravings in the present chapter.

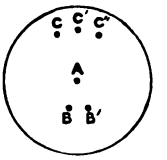

FIG. 163.

The *Eccentric Chuck* (Fig. 164) enables any portion of an article to be turned up eccentrically to its main axis, which—except by re-chucking it—cannot be done with any of the foregoing apparatus. Thus, supposing Fig. 163 to represent the outline of a piece of wood, chucked and turned up; in the natural course of things it revolves round its centre, A, and, without being chucked afresh, its axis cannot be brought into any other position. But with the aid of the eccentric chuck any other point, B, or C, can be made the axis of revolution; or an entire series of such points, B, B', or C, C', C'', all equidistant from A, can in turn be brought into the line of the mandril.

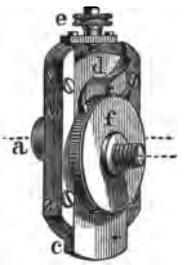

FIG. 164.—Eccentric Chuck.

This result is obtained in the following manner:—

Between the ordinary cup-chuck which carries the work and the mandril, the eccentric chuck is introducted; consisting, firstly, of two thick plates of brass (*b*, *c*) so connected together as to form a 'slide' (on the principle described above); secondly, of a circular plate (*f*) pivoted to the slide at its centre. Supposing the eccentric chuck to be screwed upon the mandril by means of the boss (*a*) at the back of the slide, and the cup-chuck with the work contained in it to be secured to the plate (*f*) by means of its screw (of which

[1] *On Lathes and Turning*, Northcott. Longmans: 1868.

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the thread corresponds with that of the mandril), the required eccentricity can be given by turning the head of the driving-screw (*e*), which produces the effect shown by the dotted lines. The exact distance between the old and the new axis of the work can be read off by main graduations on the slide itself and subdivisions on its screw-head. To enable equidistant points, such as c, c′, c″, to be brought in turn into the line of the mandril's axis, the plate (*f*) is provided with a series of notches round its edge in which a detent (*d*) catches, the plate being able to revolve only when the detent is lifted. As it is desirable to have the means of consider-

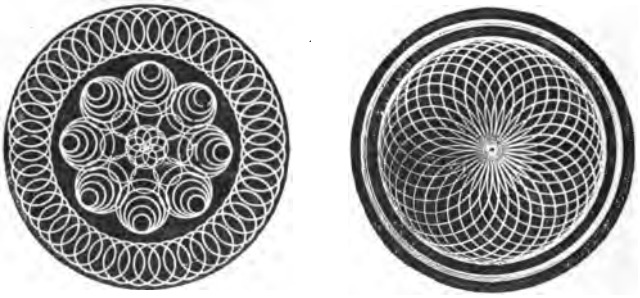

FIG. 165.—Eccentric Chuck Patterns.

ably varying the number of points in such a series, the total number of notches in the edge of plate should be one that is divisible by as many factors as possible, 96 being generally adopted. This can be divided without remainder by 2, 3, 4, 6, 8, 12, 16, 24, 32, and 48. The fact that 100 is divisible only by 2, 4, 5, 10, 20, 25, and 50 is an instance of the inferiority of a decimal system over which advocates of such a system would do well to ponder

By using an eccentric chuck in conjunction with a slide-rest, and causing the tool to trace a circle round each one of any series of such points in succession, an elaborate and occasionally pretty species of ornament can be applied to the lid of a snuff-box or other piece of face-work. It is in this

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so-called 'ornamental turning' that the eccentric chuck finds its chief application. Two specimens of patterns thus produced are given in Fig 165.

The *Oval-Chuck* has been usually described as the invention of Abraham Sharp, an ingenious English mathematician of the last century; but it should apparently be called a gradual development rather than an invention, as several forms of it, in some of which the modern principle is distinctly recognisable, are given in Plumier's engravings.

It almost requires to be seen to be understood, but a general notion of its appearance and action may be gained from Fig. 166. Its object is to impart such a motion to the work that a tool held stationary in contact with it shall at each revolution of the mandril describe an ellipse instead of a circle. The right-hand portion of the figure will be seen to bear much resemblance to the eccentric-chuck just described. A plate (*b*) has upon it a similar boss (scarcely seen in the figure), by which it is attached to the mandril; and a similar sliding-plate (*c*) has a screw for carrying an ordinary chuck containing the work, at the base of it being a wormwheel and tangent screw, which serve the same purpose as the teeth and detent of the eccentric-chuck. In passing, we may mention that these last are better omitted when the chuck is to be used for plain oval turning only, the screw being then part and parcel of the slide (*c*), so that one source of possible unsteadiness is avoided.

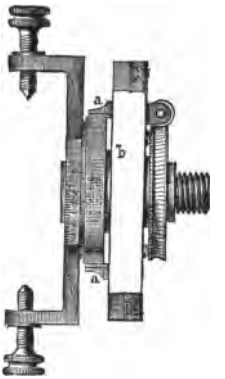

FIG. 166.—Oval Chuck.

Instead of the sliding-plate (*c*) being adjusted by the slow motion of a screw, as in the eccentric-chuck, it is made to work in its groove with perfect freedom, carrying with it

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however two guides (*a a*), which are firmly fixed to it, and which pass through slots in the plate (*b*). Entirely detached from the above plate, slide, &c., is a ring, of which the outside diameter exactly fits the space between the guides (*a a*). By means of the arms and milled-headed screws on the left of the figure, this ring can be firmly fixed to the headstock of the lathe without in any way interfering with the rotation of the mandril, the screw of which passes through the ring. As long, therefore, as this fixed ring is concentric with the mandril, the oval-chuck in no way influences the motion of any piece of work which may be attached to it, its guides (*a a*) merely sliding round the ring without being drawn out of their natural course. But when this ring is moved sideways by loosening one of the pointed screws and tightening the other, so that its centre no longer coincides with that of the mandril, it no longer allows the guides (*a a*), nor the slide (*c*) which is in connection with them, to follow a circular path. At two points, indeed, during each revolution of the mandril (when a line joining the centres of the guides is vertical, the arms and screws being horizontal when the ring is in position), the slide (*c*) is concentric with it; but after these points have been passed, the guides alternately draw the slide more and more from its natural course, till it has an amount of eccentricity equal to that at which the ring has been set. This occurs twice in each revolution; and since the effects of these two disturbances are in opposite directions, the major axis of the ellipse thus described exceeds its minor axis by twice the amount of eccentricity given to the ring. By means of graduations on any convenient part of its arms, the amount can be read off. It must of course be equal to half the difference between the major and minor axis of the ellipse. Thus, for cutting an ellipse measuring $7\frac{1}{2} \times 6$ inches, the ring must have an eccentricity of $\frac{3}{4}$ of an inch. In using it with hand-tools and an ordinary T-rest, considerable care is necessary to keep the edge of the tool at one constant height above the

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lathe-bed. Any change in the height of the tool causes a corresponding change in the direction of the ellipse, accompanied by the destruction of the work, in the manner shown to an exaggerated extent in Fig. 167.

By making use of the worm-wheel adjustment which appears in Fig. 166, face-work ornament can be produced consisting of a series of intersecting ellipses either concentric, or (by combining the eccentric-chuck with the oval-chuck) eccentric. But such complications as the latter are not to be recommended, as under any circumstances oval-chucks have much tendency to vibrate.

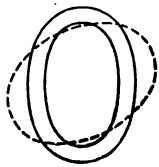

FIG. 167.

The slide-rests and the tools used with them for these 'ornamental' purposes differ greatly from those represented in the previous figures (Figs. 156 and 158). The tools—some of which are shown of their full size in Fig. 168—are sufficient for the very light cuts which alone are demanded of them, but for ordinary turning they would be nearly useless. In the slide-rest also strength and durability are apt to be sacrificed to lightness and outward appearance, and simplicity to variety in the adjustments of which it is capable. Means for regulating the height of the tool-holder are provided, and a third slide is interposed between the lower slide and the upper one. Occasionally, too, even a fourth slide and other superfluities are introduced—as in the 'spherical slide-rest,' represented in Fig. 169—by which wonderful things may doubtless be effected. But with each fresh complication an additional chance of unsteadiness in the tool is introduced, which can only be avoided by increased care in the manufacture and use of the apparatus; so that, except

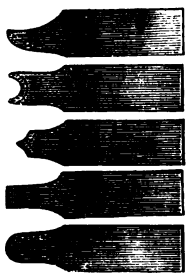

FIG. 168. — Slide-Rest Tools for Ornamental Turning.

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for the purpose of producing elaborate patterns (which are often of doubtful beauty), a slide-rest which is so constructed as to hold the tool as rigidly as possible is much to be preferred to one of great complexity.

In the ornamenting of face-work with incised patterns

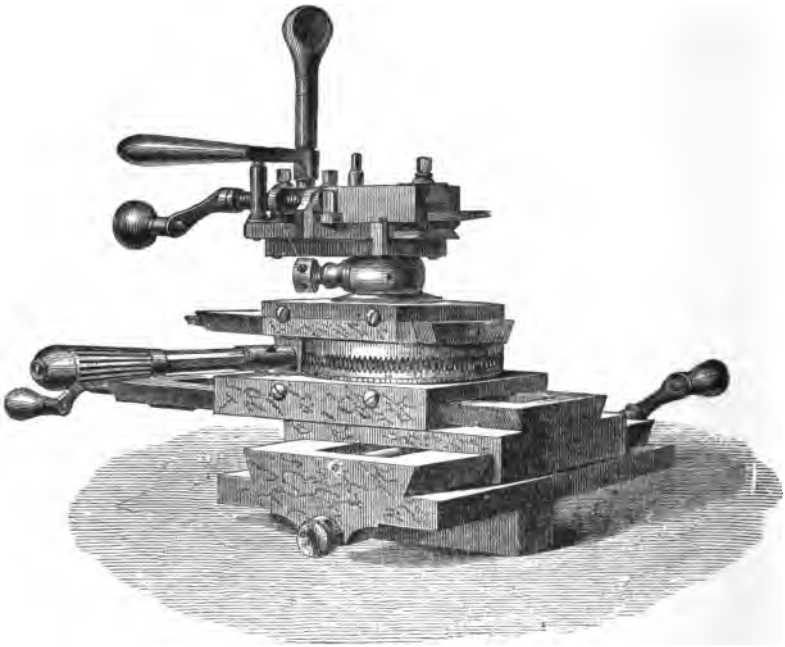

FIG. 169. - Spherical Slide-Rest.

some advantage is gained by transferring the requisite movement from the work to the tool, the process then being more nearly allied to drilling than to turning. The lathe-head and mandril then become useless, except for affording a firm and readily adjustable support for the work in hand, the graduations of the mandril pulley (on its divided plate,

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already mentioned) being used to enable each of a series of points to be brought in turn into a line with the axis of the revolving cutter. Easily divisible numbers, such as 96, 144, or 360, are chosen for the different 'scales' on the divided plate, for the same reason as for the teeth of the eccentric chuck.

Lathes intended for this kind of work are provided with some kind of 'overhead motion,' for enabling the rotation of the fly-wheel to be communicated to the tool supported by the slide-rest. This is generally done by one or other of the following arrangements. Either a light shaft is placed parallel to the axis of the mandril at some three feet above it, and this is driven directly from the fly-wheel without

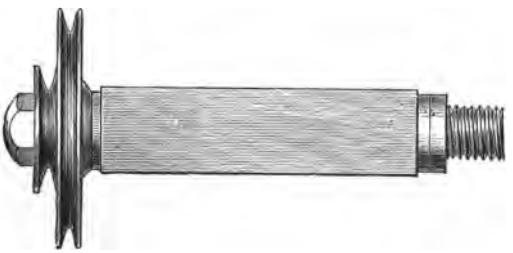

FIG. 170.—Revolving Cutter-Holder.

being in any way connected with the mandril; a second short band being then passed over a pulley on this shaft, and round the revolving cutter-holder. Or a long single band is used, which runs first round the fly-wheel, thence over two loose sheaves supported by a balanced bar above the head of the operator, and which finally descends, as before, to the revolving holder in which the cutter is fixed. Fig. 170 represents a *Revolving Cutter-Holder*, which can be used in this way for either plain or slot drilling, for cutting grooves, key beds, &c., and for a variety of ornamental purposes. It consists of a square shank, of a convenient length for being held in the tool-holder of the slide-rest, within

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which is a steel spindle, having at one end a grooved pulley, and at the other end a screw, and also a central hole for the attachment of the drills or cutters. These having various forms of cutting edge (examples of which are given in Fig. 171), produce by their revolutions a great variety of beaded and other patterns. Or, by substituting for these round or flat-sided drills, and giving them a horizontal motion by means of the slide-rest, grooves of corresponding sections can be cut either parallel or transversely to the axis of the work.

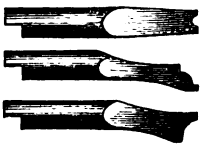

FIG. 171.
Revolving Cutters for Ornamental Turning.

Extending the system of imparting the motion to the tool instead of to the work, a slight addition to the revolving-holder just described enables us to dispense altogether with the eccentric chuck for engraving such patterns as those

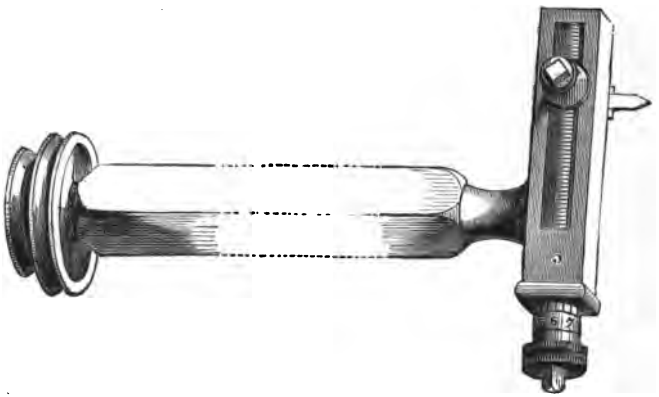

FIG. 172.—Eccentric Cutter.

given in Fig. 165. For this purpose the cutter, instead of being attached concentrically to the spindle, is fixed in a holder which can be made to travel along a cross-slide; as shown in Fig. 172. The holder can be adjusted by means

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of a milled-headed screw and can be firmly clamped at any part of the slide, graduations on the head of the screw enabling it to be accurately set, so as to describe any circle whose radius does not exceed the length of the slide. Series of intersecting circles can then be traced on the face of the work as before described, their positions being arranged with the assistance of the divided plate of the mandril instead of the eccentric chuck.

By an ingenious but slightly complicated arrangement of cutter-holder, the oval chuck also may be dispensed with

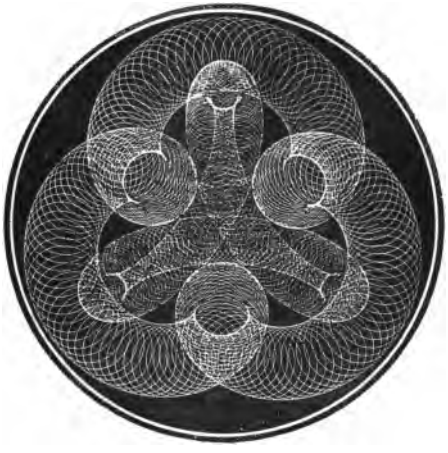

FIG. 173.—Geometric Chuck Pattern.

in similar cases, the cutter being made to travel in an elliptical path which may vary to any required extent, from a circle on the one hand to a straight line on the other. Other and yet more elaborate forms of apparatus, and also the combination of some of the above with one another and with the motion of the mandril, result in the production of face-work patterns, &c., of great complexity and occasional

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beauty. In Fig. 173 is an example of such patterns, which will serve to show the capability of the *geometric chuck*; a most ingenious contrivance, by which an endless variety of curves can be obtained. A drawing and description of this chuck, together with various other devices engraved by it, may be found in Mr. Northcott's work, already referred to, where the reader will also find an account of an excellent substitute for the *Rose Engine*, by which such patterns as Fig. 174 are produced. The cases of watches, to which, on account of their curvature, the ordinary eccentric patterns are inapplicable, are generally ornamented in this way, the waviness being formerly produced by attaching to the mandril a circular plate with the requisite number of notches round its edge. Against this a small roller was made to bear, which, entering each of the notches in turn, caused a slight corresponding lateral motion on the part of the mandril, the headstock being so arranged as to admit of it. Thus the work was made to vibrate or 'chatter,' so that a fixed tool produced upon it a pattern with the same number of waves as the plate or 'rosette.' In the 'rose-cutting instrument' referred to, the cutter is made to vibrate, the work being stationary; an arrangement which has obvious advantages.

FIG. 174.—Rose Engine Pattern.

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CHAPTER VI.

ON POWER-LATHES.

THE transition from foot-lathes to power-lathes might seem as if it ought to be accompanied by a diminution in the number of their working parts, although of course they must be of greater strength and weight. A glance at the engravings in the present chapter, however, will soon dispel any such idea—the cause of their apparent complication being, broadly speaking, twofold. In the first place, most of the work which is performed with them requires a very slow speed; and for the transmission of this the leather belts by which the power is, as it were, laid on from the engine, or other prime mover, are not well adapted. Consequently, their comparatively high velocity must be much reduced before it is communicated to the work; and although this is in almost all cases partially effected by means of a 'counter shaft,' arrangements for still further exchanging speed for power are affixed to the headstock of every power-lathe.

Secondly, still greater complications are rendered necessary by the universally prevalent practice of making power-lathes 'self-acting'—that is to say, providing them with some mechanical means of giving the proper feeding motion to the tool. This may be effected through the agency of the slide-rest in several different ways, one of the most frequent being that adopted in screw-cutting lathes of connecting it with a long and accurately pitched screw (the 'guide' or 'leading screw'), of which the axis is parallel to the lathe-bed. For this purpose the driving speed must be still further reduced, and the proportion which the revolutions of the leading screw bear to that of the mandril must be definite and capable of adjustment; conditions which are most easily and certainly fulfilled by connecting them

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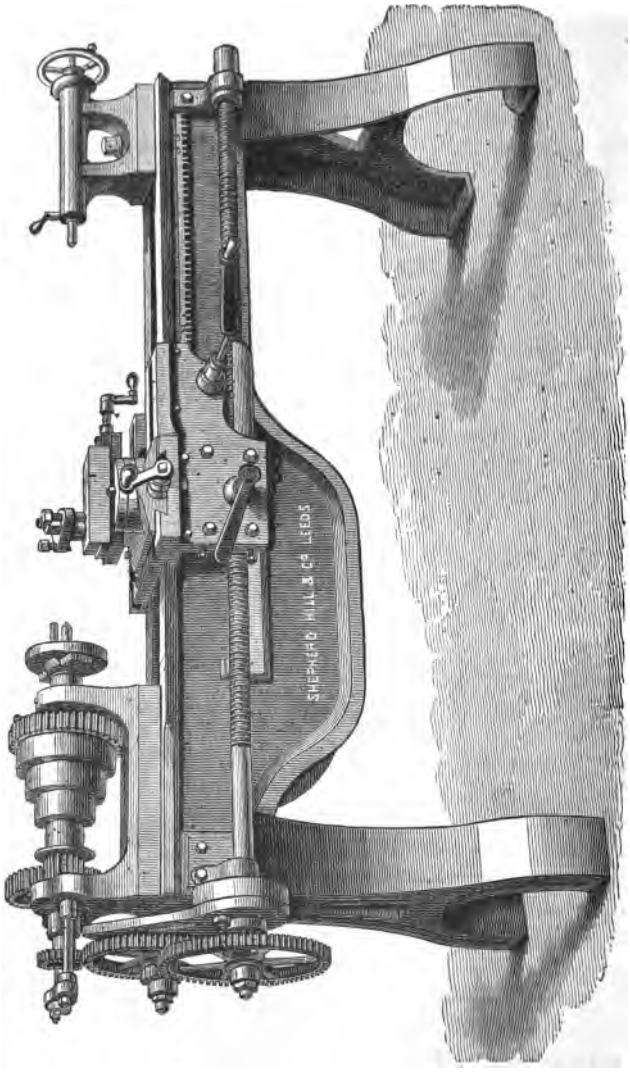

FIG. 175.—8-inch Screw-cutting Gap Lathe.

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together by a train of 'change wheels.' These, especially when a lathe is also provided with the 'self-acting rack-traversing motion,' hereafter described, give at first sight an appearance of great complexity. But this is soon dispelled when each set of parts is examined independently of those which, although very near neighbours, are in no way related to it. Each, however, of the above self-acting arrangements requires corresponding additions to be made to the slide-rest, which consequently assumes proportions very different from those of its foot-lathe representative shown in Fig. 156. But it will be better to defer the detailed consideration of the various parts of a self-acting slide-rest till the description of one or two of the lathes themselves have rendered evident the necessity for these modifications in its construction.

Fig. 175 shows an 8-inch *Screw-cutting Gap Lathe*, which will serve to explain the double-geared headstock by which the requisite slowness of motion is given to the mandril, and also to show the position, &c., of the leading screw, and the change wheels by which such lathes are rendered self-acting. With the difference between a plain and a 'gap' lathe we will not trouble ourselves at present. First, then, as to the *Double-geared Headstock*, of which a plan is given in Fig. 177, the lower part of the drawing being in section so as to show the form of the mandril, which bears but little resemblance to that of the foot-lathe given in Fig. 118. Both its bearings in the headstock are conical, the front or right-hand cone being formed on the mandril itself, the hinder or left-hand one being a loose conical bush carefully fitted to it. This, among other advantages, enables an accurate fit to be maintained between the mandril and the headstock, without having recourse to plummer-blocks, which would be necessary if the bearings were cylindrical. On the mandril—of which the whole of the central part is of uniform diameter—is a loose conical pulley, to the small (hinder) end of which a pinion is attached. These are in no way connected

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with the mandril, but revolve freely upon it. Fig. 176 will explain the arrangement, F and G being the conical pulley and pinion, inseparable from each other, but not connected with the mandril. In front of the large end of F is the spur-wheel L, which is connected with the mandril, and always revolves with it; and gearing into this is a pinion K, keyed upon a short shaft parallel to the mandril. Fixed upon this shaft there is also a spur-wheel H, gearing into the pinion G. The effect of driving the pulley F at a quick speed by means of a leather belt (of which a portion appears

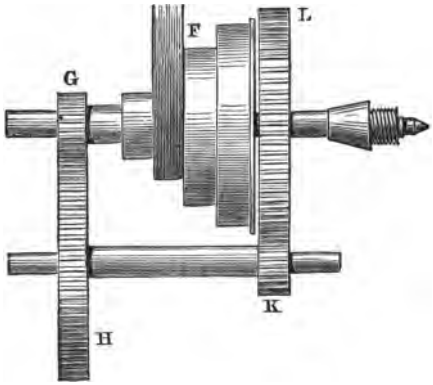

FIG. 176.

in the diagram) is thus to make H revolve less rapidly; the pinion K, which runs at the same speed as H, still further reducing it in its transference to the mandril through the spur wheel L. To enable the mandril to be driven at a quick speed when required, a bolt can be screwed through L into the face of the pulley F, thereby connecting it with L, and through L with the mandril. H and K must then be thrown out of gear, which can be done either by sliding the shaft which carries them in the direction of its length, or by the somewhat neater expedient of supporting it in eccentric bearings instead of directly in the headstock itself. The

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headstock represented in Fig. 177 is fitted with this arrangement, the portions of the framing which would naturally conceal the discs (B and B′) being removed; as also are parts of the pulleys, &c., for the purpose of showing the mandril, as already explained. One of these discs (B) is likewise shown in section, so as to exhibit the position of

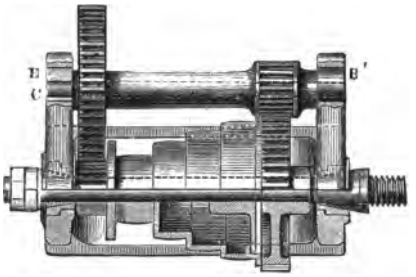

FIG. 177. Plan of Headstock.

the shaft C, when the toothed wheels which it carries are in gear with those on the mandril. When the wheels are out of gear, the shaft occupies the position indicated by the dotted lines in the sketch (Fig. 178), in which C represents the end of the shaft under the former condition, and B the disc in which it is supported eccentrically, of which the 'throw' need only exceed the depth of the teeth of the wheels by a sufficient amount to insure their clearance. It will be observed that this system, which is now very largely used, not only for lathes, but also for drilling machines, &c., admits of the headstocks being somewhat shorter than is required for the sliding arrangement alluded to above.

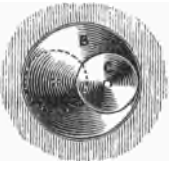

FIG. 178.

In a plain 'screw cutting' lathe—and it was for the purpose of originating screws that Mr. Henry Maudslay, at the commencement of the present century, devised the self-acting lathe—a shaft with an accurate *Leading Screw* cut

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upon it is supported (in bearings at its ends only) in some convenient position truly parallel to the axis of the mandril. In Fig. 175 it is placed in front of the lathe-bed. In Fig. 182 it is between the cheeks of the bed, and therefore cannot be seen. In either case the connection between the slide-rest and the leading screw can be made or broken at pleasure, and any requisite proportion between its speed and that of the mandril can be obtained by properly combining the *Change Wheels*; a set of which (consisting of about $1\frac{1}{2}$ or 2 dozen) is provided with every lathe of this kind.

The arrangement can be clearly seen in Fig. 175. One of the wheels is attached to the end of the leading screw, and the mandril, which is prolonged for that purpose beyond

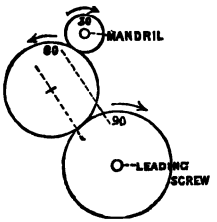

FIG. 179.

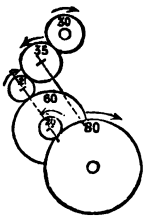

FIG. 180.

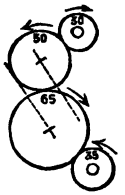

FIG. 181.

the left-hand bearing of the headstock, carries a pinion. Two horizontal pillars with a cross-piece between them give the requisite support to the projecting end of the mandril, and assist its front bearing in taking end thrust. One or more change wheels mounted on an adjustable *Radial Arm* or *Tangent Plate* then complete the train connecting the mandril with the leading screw. The exact pitch of the leading screw being known (it has generally from 1 to 4 threads to the inch), a simple calculation shows what number of threads to the inch will result from using any given combination of wheels. For ordinary pitches, however, a table [1] is provided with each lathe, which shows at a glance the wheels which will give the proper result. But the

[1] See Appendix. Table VIII.

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correctness of the table, or the increase or diminution of speed—and by consequence the theoretical loss or gain of power—due to any other train of wheels (as, for example, the wheels of the double-geared headstock just described) is so easily calculated, involving only a knowledge of simple arithmetic, that all who study or use such lathes should be familiar with the process, which the examples in the diagrams (Figs. 179, 180, and 181) will render clear.

Of these the first and second arrangements are for cutting ordinary or 'right-handed' screws, as is evident from the direction in which the leading screw is driven being the same as that of the mandril. In the third (Fig. 181) the wheels are so arranged as to cut a 'left-handed' thread. The number of threads cut per inch, if there are three to the inch in the leading screw, will be respectively:—

$3 \times \frac{80 \times 90}{30 \times 80} = 9$ threads per inch. (See Diagram, Fig. 179.)

$3 \times \frac{35 \times 21 \times 60 \times 80}{30 \times 35 \times 21 \times 20} = 24$,, (,, ,, Fig. 180.)

$3 \times \frac{50 \times 65 \times 35}{30 \times 50 \times 65} = 3\frac{1}{2}$,, (,, ,, Fig. 181.)

Running along the front of the lathe bed above the leading screw, in Fig. 175, a rack may be observed. Its object is to enable the slide-rest to be moved along the lathe bed (or 'traversed') by hand when it is not required for screw-cutting, and also in screw-cutting to enable the rest to be run back quickly before commencing a fresh cut. A pinion (not seen in the figure) gears into this rack. In some cases the screw itself is made to serve for a rack, a worm-wheel being substituted for a pinion; but as so much depends upon the accuracy of the leading screw, all unnecessary wear and risk of injury to it should be avoided.

The construction of the loose headstock which carries the *Back Centre* will be intelligible from the section of the foot-lathe poppet head given in Chapter V. (Fig. 118).

Fig. 182 shows a larger lathe of somewhat different con-

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struction from the preceding one. The bed is of uniform depth throughout its length, and the leading screw, as has already been pointed out, is placed between the cheeks of the bed, so that it cannot be seen in the engraving. Where a duplex slide rest is used—an invention of Sir J. Whitworth's, by the adoption of which much time may be saved—this central position of the leading screw has great advantages. The double tool-holders can be clearly seen in the figure; their action will be explained when we come to consider the self-acting slide-rest generally.

In this, however, as well as in the lathe shown in Fig. 175, the slide-rest depends for its self-acting motions upon the leading screw only; and when this is the case, its original accuracy (as previously stated) cannot long be maintained. This is to some extent due to the greatly increased strains to which it is subjected when used for turning heavy work instead of for cutting the threads of screws only. But, even if every possible care be taken in this respect, a still more fertile source of error remains, from the fact that the bulk of the work in almost every lathe is performed within a short distance of the mandril, so that this part of the screw becomes much more rapidly worn and deteriorated than the remainder. This has led to the introduction of self-acting apparatus for giving motion to the slide-rest by means of the longitudinal rack, to which, in its application to hand-traversing, attention has already been directed. The gearing required for this purpose gives an additional appearance of complication to lathes which are provided with it, which are known as *Self-acting, Surfacing, and Rack-traversing* lathes; the tools attached to their slide-rests being capable of being driven with a slow 'traversing' motion parallel to the lathe-bed, at right angles to it for 'surfacing,' or diagonally, by an ingenious combination of the two, for 'taper' turning. For these purposes a longitudinal *Back-shaft* is placed behind the bed, being supported (at its ends only) in the same manner and in much the same position at the back, as that in which

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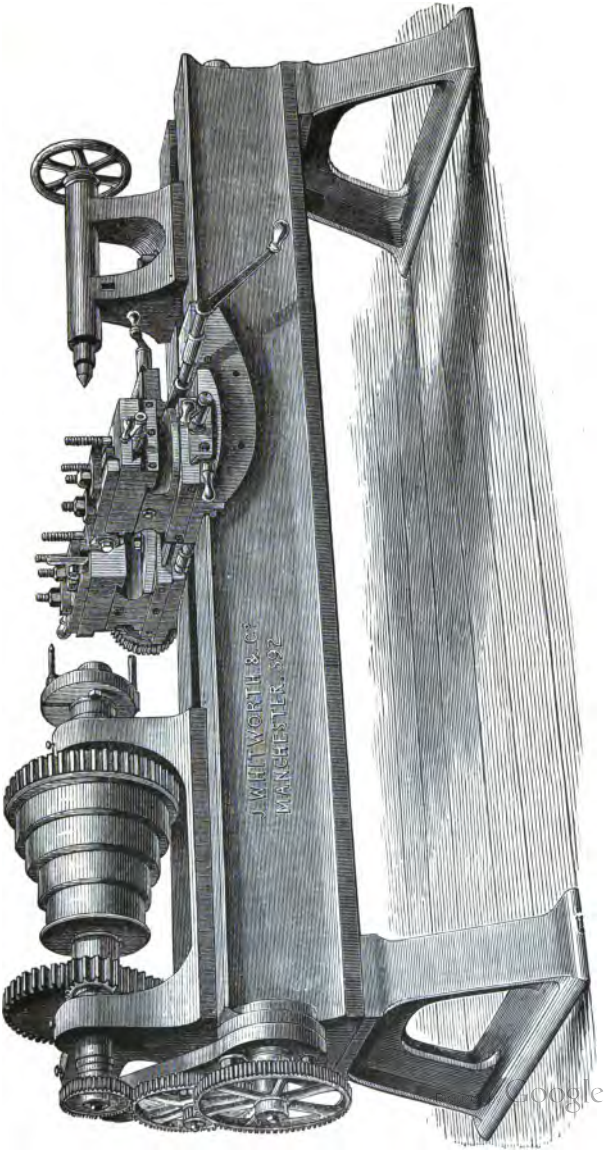

FIG. 182.—10-inch Duplex Lathe.

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the leading screw shown in Fig. 175 is supported in front. But this shaft, instead of having a screw-thread cut directly upon it, carries a short worm, which, whilst it can slide freely in the direction of its length, is compelled always to revolve with it, the shaft being provided with a longitudinal groove, and the worm, with a feather, for this purpose. In this way any part of the back-shaft can be made to serve as a worm or tangent-screw to a worm-wheel which is carried by the slide-

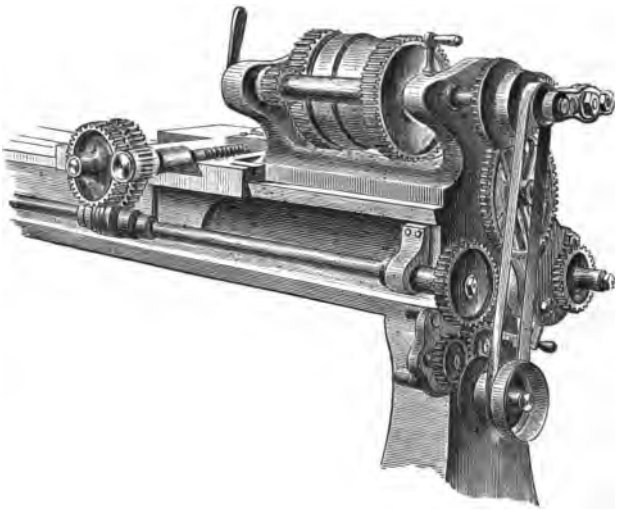

FIG. 183.—Back View of Rack-traversing Lathe.

rest, whilst at the same time the rest can be made to traverse by hand, for which special arrangements would be required if the screw were continuous.

The manner in which the various motions are communicated through the worm-wheel to the turning-tool will be fully explained when we deal with the slide-rest; at present, we will confine ourselves to describing the ordinary method of driving the back-shaft, and of varying its speed, the arrangements for which are so clearly shown in the accom-

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panying engraving that our task will be a comparatively easy one. This (Fig. 183) represents a back view of the headstock end of a rack-traversing and surfacing lathe, and in it the back shaft worm and worm-wheel just mentioned can be plainly seen. It is also evident that the slide-rest, which carries the worm-wheel, toothed wheel, and pinion, cannot be moved along the bed without taking the worm upon the back-shaft with it. This, therefore, bridges over the main difficulty in transferring a portion of the power from the mandril to the tool—namely, that arising from the variable position of the slide-rest.

Tracing the course of the motion from the worm and shaft towards the mandril—although it is of course not transmitted in this direction, but in the opposite one—we observe in the first place a spur-wheel made fast upon the extremity of the back shaft. Into this gears one or other of a pair of smaller spur-wheels, according to the direction in which the back-shaft has to be driven. These wheels are supported, not directly upon the end standard, but upon a rocking-frame, which can be moved backwards and forwards through a short distance by means of a bar terminating in a handle at the front of the lathe. Upon the position of this frame, as we have said, the direction of the rotation of the back-shaft depends. For the two wheels which it carries are constantly in gear with one another, one of them being also constantly in gear with a pinion attached to the conical pulley which appears below these toothed wheels in the engraving. When therefore the frame is in one position, the wheel which is always in gear with the pinion is brought also into gear with the backshaft-wheel, the second wheel running idle, but when the position is reversed this second wheel is brought into the train, and the movement of the shaft is consequently reversed.

From the upper conical pulley to the lower one a belt transmits the motion, the three 'steps' in each affording the means of driving the back-shaft at three different rates

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of speed, whilst a spur-wheel carried by the radial arm establishes the connection between the upper pulley and the mandril; the pinion on the overhanging end of the latter, by which it will be remembered that the requisite motion is obtained from it for driving the leading screw in screw-cutting, serving the like purpose, when not so required, in the case of the traversing and surfacing gear.

With reference to the use of the 'gap,' already mentioned, it will be remembered that the chief limit to the capacity of a foot lathe was stated to be the height of the 'centre' (of the mandril) above the bed. A gap is an expedient for extending this limit, and thus enabling a lathe to take in articles of much greater diameter (if of moderate length) without materially increasing its weight or general dimensions. For this purpose the bed is cast with a gap just in front of the end of the mandril, where a corresponding bend may be observed on its under side in Fig. 175. When the gap is not required, a loose piece, fitting closely into the opening in the cheeks, gives the lathe an ordinary flush bed. In the figure referred to this piece is shown in position, and its fit is so accurate that the gap can hardly be recognised. Although a gap is undoubtedly useful, it is not altogether an unmixed advantage, inasmuch as it offers continual temptation to the workman to overtask the power of the working parts of a lathe, by enabling him to use it for heavier work than is advisable. The bed itself can of course be strengthened to any required extent by properly disposing an increased weight of metal, and in large gap-lathes the projection below the bed not unfrequently extends quite down to the floor of the shop.

But when the treatment of work of large diameter is the regular and not the exceptional duty of a lathe, the increase in size should not be confined merely to the distance between the mandril and the bed, but should be extended to all its working parts. As moreover it may often be necessary to turn up articles of which the length as well as the diameter

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is considerable, it is desirable to have the means of extending the limit which is set by the width of the opening in the bed of a gap lathe. These requirements are fulfilled by what is known as a *Sliding Break Lathe*, of which an example is give in Fig. 184. In this the bed consists of two separate parts—a bed-plate, which is of the full length of the machine, and of which the flat upper surface is kept at a sufficient depth below the mandril to enable the largest piece of work which the lathe can contain to run clear of it; and an adjustable upper part, or bed proper, which carries the slide-rest and moving headstock upon its surface after the manner of an ordinary lathe bed, but of which the length is comparatively small. The width of the base-plate shown in our engraving is greatly increased in the neighbourhood of the fast headstock, to enable the slide-rest, when mounted on a separate stand, to be used at a greater distance from the axis of the mandril than is possible when it is supported by the sliding bed—but in some break lathes this arrangement is dispensed with. The width of the 'break' or 'gap' can be adjusted to suit the length of the work by moving the sliding bed bodily along the surface of the bed-plate; the back centre remaining always truly in a line with the axis of mandril. This traversing motion of course puts fresh difficulties in the way of rendering the slide-rest self-acting. These, however, have been overcome by various expedients, consideration of the details of which would not be profitable in such a work as the present, so that we can only recommend the reader who is interested in them to examine the machines themselves when he has the opportunity.

The increased number of toothed wheels at the back of the headstock—which certainly at first sight gives a somewhat complicated appearance to the lathe, Fig. 184—is due in part to the length of the train by which the necessary reduction of speed for the feed motion is obtained, and partly to the fact of the headstock itself being 'treble geared,' the face-plate being driven, when the work is of large diameter,

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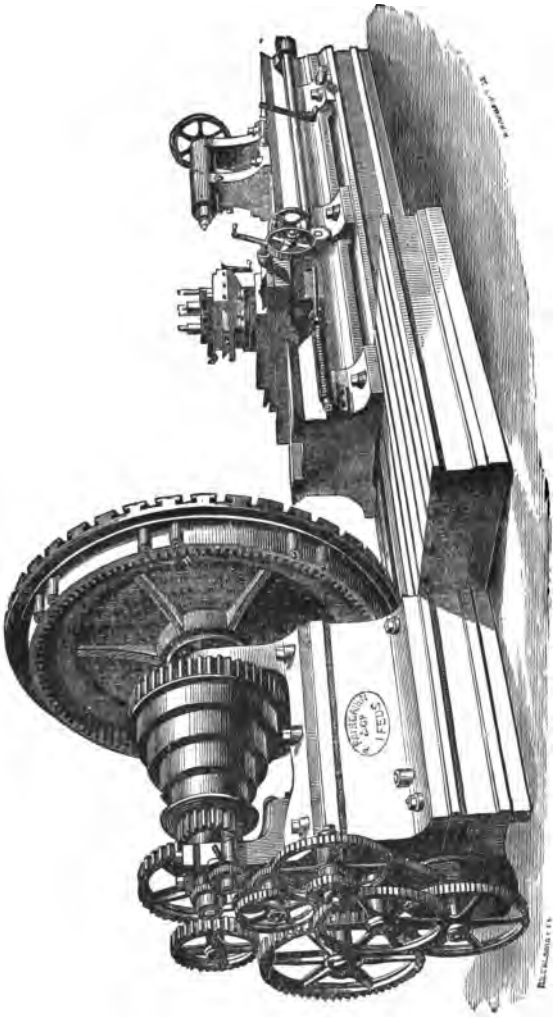

FIG. 184.—Break Lathe.

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by a pinion gearing with the annular wheel at its back instead of by the mandril. These lathes are occasionally of very large size, the dimensions which determine their powers being, first, the height of the headstocks; secondly, the length of the bed; and thirdly, the diameter and length of the work which can be taken by the gap or break. In the figure the height of the headstocks (above the upper bed) is 21 inches, but this lathe is by no means a large specimen of its class; others ranging as high as 48 inches in the height of the headstocks, with 20-foot beds and breaks capable of receiving work 14 feet diameter and 3 feet 6 inches wide.

When, however, articles which have to be turned are of such large size as regards their diameters, they are, more often than not, of but small width, in which case they can almost always be securely fixed without the assistance of the back centre. For these, therefore, the sliding bed may be entirely dispensed with, and the lathe may be greatly simplified and reduced in length. A small lathe of this kind—which is known as a *Face Lathe*, or *Surfacing Lathe*, from its principal duty being that of 'surfacing,' rather than 'traversing'—is represented in the accompanying engraving (Fig. 185). The slide-rest, which is of a very simple form, is provided with a base of sufficient height to bring the tool to a level with the axis of the mandril. It is made self-acting (in this case in the direction for 'surfacing' only) by establishing overhead communication between the hinder end of the mandril and the cross-slide of the rest; a light chain being passed from the weighted arm at the front of the rest, over two sheaves, one of which is fixed above the slide-rest, and the other above the horizontal arm at the hinder end of the headstock. This arm receives an oscillating motion from a cam attached to the overhanging end of the mandril, which it thus imparts to the weighted arm of the slide-rest; from which it is transferred, through the pawl and ratchet-wheel at the end of the horizontal screw, to the tool contained in the tool-holder. The feed thus obtained is of

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course intermittent, but it can be varied considerably by altering the points of attachment between the extremities of the chain and the arms, which are slotted for this purpose.

When intended for surfacing work of very large diameter, it is advantageous for the speed of lathes of this kind to be duly proportioned to the distance from the axis at which the tool may be working, and they are sometimes provided with self-acting apparatus by which this proportion is maintained. If the speed be not varied, it is obvious that the duty per-

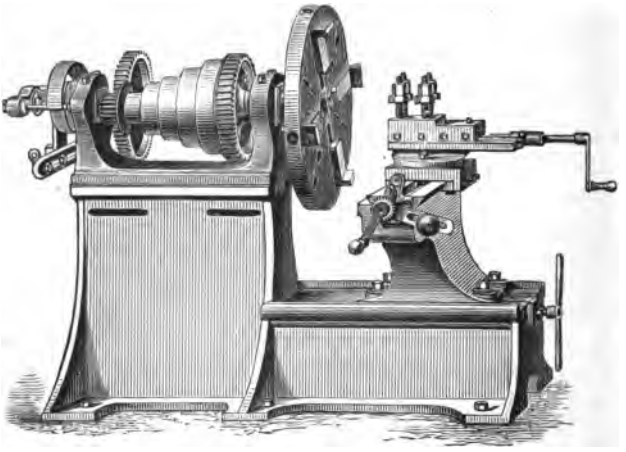

FIG. 185.—Face Lathe.

formed by both the lathe and the tool is much more severe when the cut is being taken from the outer extremity of the work, than when the central portions are being operated upon. So that in face lathes of any considerable size, treble-gearing, or the means of driving the face-plate by a large toothed wheel attached to its back, such as that seen in the break lathe (Fig. 184), becomes an absolute necessity. The above-mentioned capabilities of break lathes indeed sink into insignificance, when compared with those which face lathes

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occasionally possess. Machines of this kind with 14-foot face-plates, capable of turning articles up to 20 feet in diameter, may be obtained from any manufacturer of engineers' tools, and in bygone years the present writer was familiar with a face lathe capable of taking in work up to a diameter of 40 feet. But this was intended for a special purpose—that of operating upon railway turn-tables (which, however, it has since become customary to turn when in a horizontal instead of in a vertical position)—and for special purposes we have at present arrived at no limits in respect of size which would be recognised by our machine makers as fixed and impassable.

The point to which the growth of power-lathes has now attained is well illustrated by the following particulars of two which have been quite recently designed and made in the Royal Gun Factories at Woolwich. Each of these is intended to take in a piece of work having a maximum diameter of 12 feet and a total length of 36 feet, their main dimensions and approximate weight being :—

Height of centre of mandril above the bed	6 feet
Total length of bed	60 feet
Length of fixed headstock	12 feet
Diameter of front bearing of mandril	18 inches
Length of ,, ,,	36 inches
Length of leading screw, over all	52 feet 3 inches
Diameter of ,,	7 inches
Weight of fixed headstock	about 55 tons
,, moveable headstock	about 18 tons
,, slide-rest and saddle	about 15½ tons
Total weight	nearly 300 tons.

The general appearance of a self-acting slide-rest when in position on the bed of an ordinary screw-cutting, rack-traversing, and surfacing lathe is shown in Fig. 186. The front of the bed is provided with a leading screw and rack, and the back of it with the grooved shaft and worm seen in Fig. 183, to all of which attention has already been directed.

First, with regard to the means of establishing the con-

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nection between the rest and the leading screw—connection which must of course be capable of being made and broken at pleasure. This was formerly done by clasping the screw between the two halves of a horizontally divided nut, which was attached to the slide-rest, and of which the upper and lower portions could be brought together or separated by raising or depressing a lever handle in front of the rest. The lever handle may be observed in the engraving, Fig. 186, projecting below the bed of the lathe towards the left-hand side of the rest; but it now acts upon a divided nut of increased length, of which one half (the lower) is entirely omitted. The mode in which it raises or depresses the

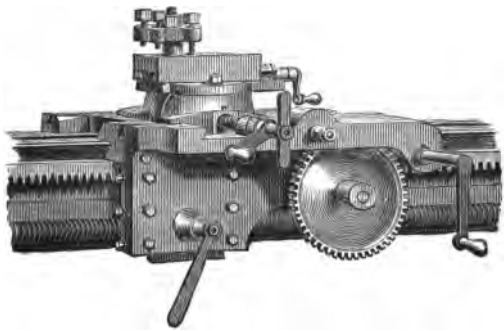

FIG. 186.—Self-acting Slide-Rest. General View.

upper half will be intelligible from the side view, Fig. 188. Careful study of the different parts in the three figures, 186, 187, and 188, in conjunction with the back view (Fig. 183), will almost render verbal description unnecessary; especially if the present slide-rest be compared with that which is shown upon the bed of the screw-cutting lathe (Fig. 175), of which the construction is more simple, inasmuch as its movements, with the exception of that derived from the leading screw, are only producible by hand. In Fig. 188, then, it will be observed that the half nut (B) is

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attached to a vertical slide (C), which is there shown partly in section, so as to exhibit the eccentric pin (D) by which it

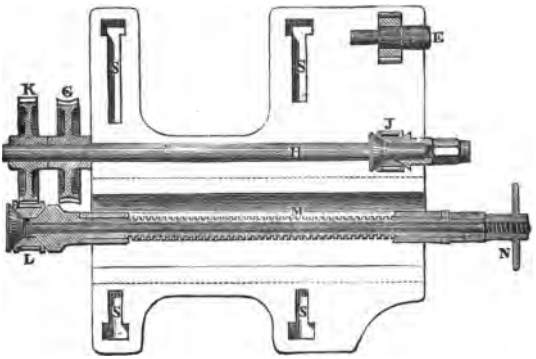

FIG. 187.—Self-acting Slide-Rest. Plan of Saddle.

is worked. When therefore the lever handle is in the position which it there occupies, the half nut is raised clear

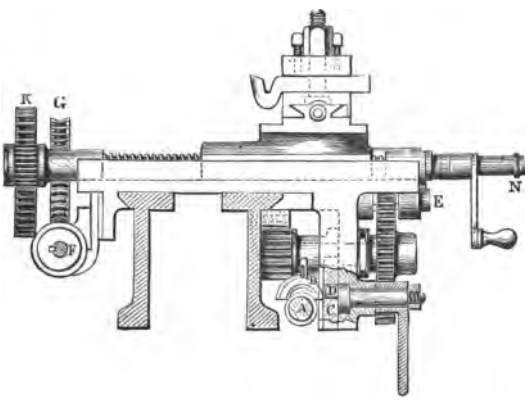

FIG. 188.—Self-acting Slide-Rest. Side Elevation.

of the leading screw (A); when on the other hand it has been moved to that in which it appears in the perspective

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view (Fig 186), where the lower part of the slide may be noticed projecting below the vertical portion of the 'saddle,' the screw and the nut are brought into contact.

But except for cutting screws, it is preferable—as we have before explained—to give this longitudinal or 'traversing' motion, by means of the rack, instead of by the leading screw. In order to do this by hand, it is only necessary to turn the winch-handle on the extreme right of the rest (in Fig. 186), which fits into the socket of the spindle (E, in Figs. 187 and 188), and thus drives a pinion gearing into the spur-wheel, which appears in the first and last of these figures. At the back of this wheel is another pinion gearing into the rack. To make this traversing motion automatic, all, therefore, that is necessary is to drive the spur-wheel from the shaft at the back of the bed ; which is easily effected through the medium of the worm-wheel (G), and the shaft (H), which carries a pinion (J) gearing with the spur-wheel. Ready means must, however, be provided for disconnecting the pinion (J) from its shaft, and thereby arresting the motion of the slide-rest ; and the method of doing this—which obtained for Messrs. Shepherd & Hill a well-earned prize medal at the Great Exhibition of 1851—is one of great simplicity and beauty. The pinion, which is bored so as to fit loosely upon the shaft (H), is deeply countersunk on both sides, and is placed loose against a conical shoulder fixed upon the shaft. The conical face of this shoulder fits into the countersunk pinion on one side, and the face of a loose conical collar fits into it on the other. On drawing these two cones together, therefore, by means of a nut working on the screwed end of the shaft (H), the pinion becomes firmly gripped, and is compelled to revolve with it ; whilst on slackening the nut (which appears in front of the rest in Fig. 186) it is instantly released.

A precisely similar arrangement is adopted for throwing in or out of gear the pinion (L), by which this rest can be made self-acting for 'surfacing.' This pinion receives its

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action from the spur-wheel (K), which is keyed upon the shaft (H) just behind the worm-wheel (G). When clipped between its cones, it drives the cross-slide screw (M) either backwards or forwards according to the position of the rocking-frame upon the end standard of the lathe, as, it may be remembered, was pointed out when we were describing, with the assistance of Fig. 183, the means by which the back shaft itself is driven. But, in the present case, the pinion is at the back of the lathe; and since it would be highly inconvenient to have the nut there also, the cross-slide screw is made hollow, and a rod, attached to the hinder cone, is passed through it to a T-handle (N) in front. The nut at the end of the shaft (H) was till lately provided with a similar handle, but a hexagonal nut, which can be readily turned with a spanner, has been found to be more convenient.

The arrangement for taper-turning, already alluded to, is as follows: Connection is established between the leading screw and the back shaft by a second train of change wheels placed at the right-hand end of the bed, in the manner shown in Fig. 189. The traversing motion being then taken from the leading screw, and the surfacing motion simultaneously from the back-shaft, a diagonal resultant is obtained, the proportion between the two motions (or, in other words, the amount of taper) resulting from any combination of wheels being readily calculated in the manner explained above.

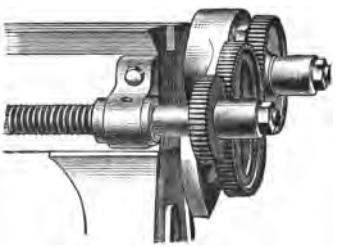

FIG. 189.—Gearing for Taper-turning. Front View.

In turning up a long shaft or any similar piece of work of which the diameter is insufficient to give the necessary rigidity, a back-stay, such as Fig. 190, is frequently attached to the saddle, so that it accompanies the slide-rest in its

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traverse, and is always favourably placed for giving the requisite support. The T grooves marked s in Fig. 187 are for the purpose of enabling this to be bolted down to the saddle.

In the Duplex lathe of which we have given an engraving on a former page (Fig. 182), the principle of making the whole of the upper part of the slide-rest in duplicate is adopted. The two ends of the cross-slide screw then have their threads running in opposite directions—one being right-handed and the other left-handed—so that the two tool-holders advance towards the axis of the work or retreat from it simultaneously. It is of course necessary to reverse the position of the tool or tools at the back of the lathe; in these, as in other slide-rests, two being frequently fixed in each tool-holder, of which one gives a roughing and the other a finishing cut. The great saving of time and labour which has resulted from the introduction of the 'Duplex' system has led to its almost exclusive adoption at Sir J. Whitworth's works. The fact of the strains upon the work being balanced when its two opposite sides are attacked equally, is undoubtedly much in its favour.

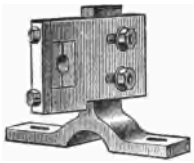

FIG. 190.—Slide-rest Back-stay.

Of the *Chucks* used with power-lathes one or two examples may have been noticed above in our engravings of the lathes themselves—such as the *four-jaw Chuck* on the mandril of the Face lathe (Fig. 185). With the Break lathe (Fig. 184) a large-sized *Face-plate* is shown; but this, unlike the generality of chucks, is attached permanently, so that it may be considered to form part of the lathe itself. The way in which it is driven by direct gearing has already been pointed out. The strengthening ribs behind it, and the T-grooves in front (in lieu of slots passing through the body of the plate, as in Fig. 127), should also be observed.

Self-centering Chucks, similar in principle to those men-

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tioned in Chapter V., are also employed with power-lathes. But for general usefulness in the secure attachment of heavy articles which are to be carried by the mandril only, no chuck can compete with the face-plate. Where the form of the work precludes the possibility of bolting it directly to the face, it can often be held with *Clamps*, similar to those in Fig. 128. Or an *Angle-chuck* can be used, which consists of an L-shaped casting, planed and slotted, one face of which is bolted to the plate, and the other to the work.

The *Drivers* and *Carriers*, represented in Figs. 125 and 126 (Ch. V.), have also their counterparts amongst power-lathes, which are equally widely employed for work which can have the support of the back centre. Another form of

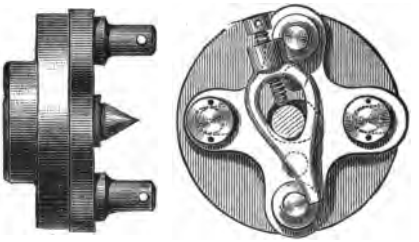

FIG. 191.—Clement's Driver (⅛).

Driver (Fig. 191) was invented many years ago by Mr. Clement of Lambeth, which possesses some advantages over the ordinary kind where the duties required of it are heavy. Its main difference consists in having two driving pins instead of one, and in having them fixed in an outer plate instead of in that which is attached to the mandril. This outer plate is capable of sliding laterally for a short distance, thus accommodating itself to any inequality in the width of the opposite ends of the carrier; by which means each of the pins is made to transmit an equal share of the driving power.

A few slide-rest tools for the lighter kinds of power-

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lathe turning are given in Fig. 192, **a** being the side view of a *Hook tool*, **b** a *Left-hand tool*, **c** a *Parting tool*, **d** an *inside tool*, **e** a *Side Facing tool* (or knife tool), and **f** a *Right-hand tool.* They are in general forged from steel bars about one inch square. Of these the hook tool is by far the most generally useful, the rough cuts, in most cases, being taken with it when the form of the work permits. In this respect

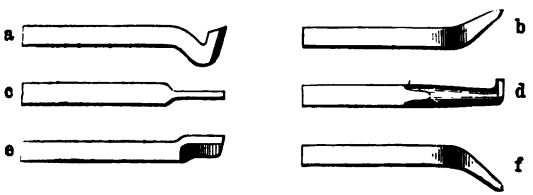

FIG. 192.—Slide-rest Tools for light work in Power-Lathes.

it corresponds to the gouge of the soft-wood turner. Portions upon which it cannot be brought to bear can, for the most part, be attacked by one or other of the remaining tools in Fig. 192, or by some modification of them. The detail of the cutting end (Fig. 193) will render the hook-tool more intelligible to those who are unacquainted with it. The

FIG. 193.—Hook Tool.

FIG. 194.—Wrought-Iron Turning from Hook Tool.

cutting edges are similar on each side of the point, so that this tool can be used with equally good effect when advancing in either direction—in other words, the feed can be either right- or left-handed. Some idea of the amount of material which it takes off can be gathered from the cutting of wrought-iron turning (Fig. 194), which is sketched to about the same scale as the tool.

When a somewhat heavier cut can be taken—owing to

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the greater size of the work which is to be turned, and the increased strength of the lathe employed for it—the form of the hook tool is generally modified, so that it resembles one or the other of the two represented in Fig. 195. The *Roughing Tool* (which is uppermost in the engraving) can be used with the feed in one direction only; but the increased width of edge, which is obtained by forming it on one side of the point instead of on both, enables it to take off a proportionately wider cutting. Where smoothness of surface is required this tool would be followed by a flat-nosed *Finishing Tool*, such as the lower one in Fig. 195.

Examples of some of the very much more powerful tools which are used for turning articles of the largest class—such as screw-propeller shafts—are given in Fig. 196. The slow speed at which these have to be run, admits of, or rather necessitates, the employment of very heavy cuts. Commencing at the top, the four tools represented are, a *Roughing Tool*, a *Spring Finishing Tool*, a *Side Facing Tool*, and a *Parting Tool*, the names clearly indicating their uses. The shanks of the originals, from which these were drawn, measured two inches on each side of the square.

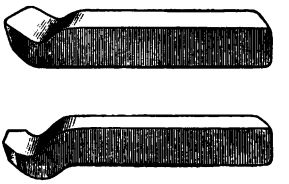

FIG. 195.—Power-Lathe Tools of Medium Strength.

Sketches of characteristic cuttings from the two uppermost of these large tools are given in Figs. 197 and 198. They are full of interest to an attentive observer.

In the first place the area of the cross section is an important factor in estimating the proportion of the total power supplied to the lathe which has been usefully expended. The original from which Fig. 197 was drawn had an area of fully $\frac{1}{4}$ of a square inch, and still larger quantities of material have sometimes to be taken off—amounting in some instances to as much as a square inch in section—

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though in such cases it is generally preferable to remove it in three or four separate cuts, by using as many different tools simultaneously.

2ndly. The form of the cross section naturally depends

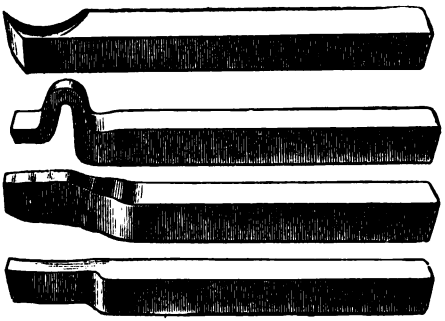

FIG. 196.—Large Power-Lathe Tools.

upon, and is an indication of, the shape of the cutting edge which produced it ; but the effect of rounding off the point of a tool is rather curious, the shaving then not sharing its

FIG. 197.—Wrought-Iron Turning from large Roughing Tool.

FIG. 198.—Wrought-Iron Turning from Spring Finishing Tool.

curvature, but merely having one of its edges thinned down to a 'knife-edge,' however great the thickness of the opposite edge may be. In the sketch, Fig. 197, this characteristic is so marked that the section approaches very nearly to a triangle.

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3rdly. The diameter and the closeness or openness of the spiral into which a cutting tends to curl itself, have each their tale to tell. The diameter is mainly dependent upon the depth of the cut and the inclination of the upper surface of the tool to the face of the work, which, in the case of heavy cuts, has an important influence upon the power expended and the spiral is either close or open, according to the extent to which the cutting edge is inclined to the direction of its feed. Fig. 198 therefore nearly approaches to a close spiral, the edge of the spring tool having been almost parallel to the axis of the work, whilst Figs. 197 and 194 have an open corkscrew-like twist, due to the angular direction of the edges of the tools which produced them.

Several other suggestive points also might be mentioned.

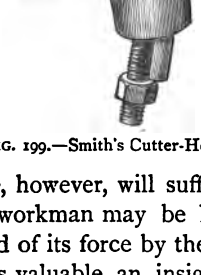

FIG. 199.—Smith's Cutter-Holder.

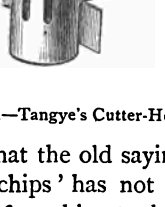

FIG. 200.—Tangye's Cutter-Holder.

These, however, will suffice to show that the old saying 'a good workman may be known by his chips' has not been robbed of its force by the introduction of machine tools, and that as valuable an insight into their performance may be gained from an intelligent study of their 'chips' as was formerly obtainable in the case of the handicraftsman from those which fell from his workbench. And to those who desire to improve upon their performances, careful consideration of details such as these, which at first sight might be regarded as too trivial for notice, cannot be too strongly recommended.

Two examples of tools with detached cutters designed

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for use with power-lathes in lieu of ordinary hook-tools are given above. In Mr. Ford Smith's pattern (Fig. 199) the round steel bar which forms the cutter is fixed at an angle of 45° instead of in line with the shank, so that each tool is either right- or left-handed, and can be used for right- or for left-handed surfacing, as well as for traversing. With Mr. Tangye's arrangement (Fig. 200) the section of the steel is such that the body of the cutter can pass through any one of three slots in the holder, and the same tool thus becomes straight, right- or left-handed, according to which of the three slots it occupies. With both of these tools gauges or templates are provided so as to insure the correct placing of the cutters and the maintenance of the proper angles in grinding

FIG. 201.—Inside Tool with Loose Cutter.

them. For this last holder many different forms of cutters are made, so that it can be used, not only for roughing, but also for smoothing, parting, screw-cutting, &c. And a useful application of the principle to inside boring, screw-cutting, &c., by the same maker is shown in Fig. 201. The economy both in steel and in labour which was pointed out as resulting from the use of the small tools with loose cutters figured in Chapter V., of course results to a much greater extent in the case of large tools. But for the fact that the diminution in the mass of the cutters increases their tendency to heat in working, they would probably have come into more general use.

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CHAPTER VII.

ON DRILLING AND BORING MACHINERY.

THE chief qualifications essential to an ordinary drilling machine for miscellaneous work are as follows: First, it must be capable of being readily connected with the shafting by which the driving power is transmitted to the various parts of a workshop, and in such a manner that the speed of the drill can be varied; secondly, it must be provided with an efficient and variable 'feed motion'; and, thirdly, it must have a perfectly firm 'table' for the reception of small articles, which must offer as little obstruction as possible to large ones. Stability and strength of framing are of course most important qualities for all machine tools, though they are not invariably to be found in the frames of drilling machines.

Fig. 202 shows a *Single-Geared Drilling Machine*, of which the upper part is a good type of these machines in their simplest form, though the lower part has some peculiarities, which we will notice directly. The *spindle* which holds the drill is vertical, as it is in all machines of this type, though for many purposes a horizontal position for it would be advantageous. Bevil-wheels and a separate horizontal shaft thus become necessary to enable it to be driven by a belt from any main line of shafting, or from a countershaft, these being invariably horizontal. The conical *speed pulley*, which, by being driven—as in the case of a power-lathe—from a similar pulley with the cone reversed, enables considerable variation of speed to be obtained, is sometimes placed within the framing, so as to bring it much

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closer to the bevil-wheels, part of the framing being then above it; but this arrangement, though somewhat more compact in appearance, has the disadvantage of almost always requiring the machine to be erected vertically under

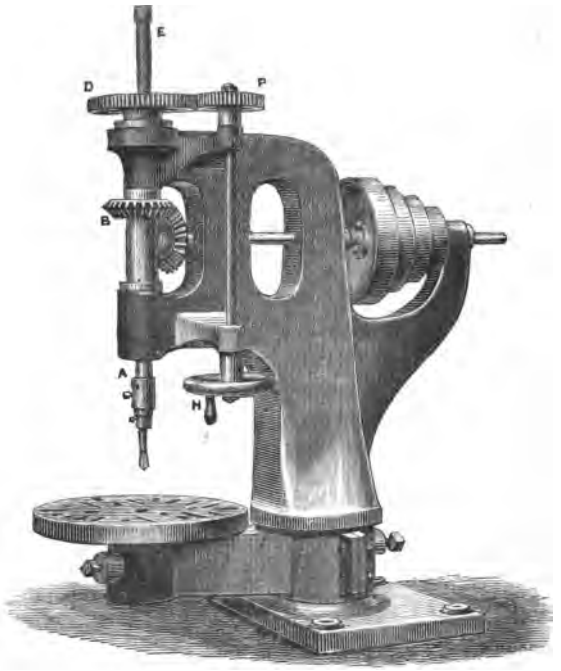

FIG. 202.—Single-Geared Drilling Machine.

the driving shaft, and parallel to it, to enable the belt to run clear of the framing.

This framing, and also that of the 'radial drilling machine,' which will be found a few pages farther on, should be noticed, being good examples of the excellent system of casting them hollow and in one piece, which was introduced

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some years ago. To turn out these complicated castings without defects, and of uniform thickness, requires a large amount of skill in the moulder's difficult art.

This machine is provided with a 'screw-feed,' worked by hand, of which the general arrangement appears with great distinctness in the engraving (Fig. 202); the effect of turning the hand-wheel (H) being obviously to raise or lower the drill spindle. But the construction of the several parts—which is not quite so simple as might at first be supposed—will be rendered more intelligible by the section (Fig. 203), in which the letters refer to the same parts as in the preceding figure. The spindle (A), the lower end of which receives the drill, slides freely through the elongated boss, or 'pipe,' of the horizontal bevil-wheel (B). Inside this boss a feather, fitting loosely into a groove (G) upon the spindle, compels it to revolve with the bevil-wheel without interfering with its independent vertical motion. But this vertical or 'feed' motion is controlled by the long screw (E), which is so connected with the upper end of the drill-spindle (A) as to be able to raise or lower it, either when at rest or when revolving, without itself sharing the revolution; its tendency to do so being checked by a longitudinal groove

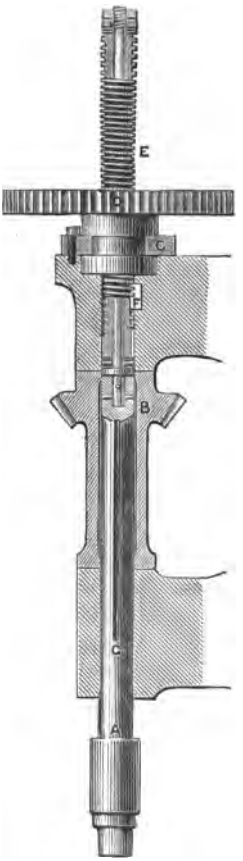

FIG. 203.
Section of Drill-Spindle.

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and a feather (F) fixed within the framing. In order to raise the point of a drill fixed in the spindle (A), we have therefore merely to draw the screw (E) upwards by means of any convenient form of nut; the most convenient in this case being a spur-wheel (D) with a female screw cut through its boss, which can then be worked by a pinion (P) and hand-wheel (H), within easy reach of the workman. But besides raising and lowering the drill, it is necessary to be able to put considerable downward or 'feed' pressure upon it. This can be done by merely continuing to turn the hand-wheel (to the right, the feeding screw being 'left-handed'), after the drill has been brought into contact with the work, the spur-wheel being prevented from rising by a split-collar (C) which fits into a horizontal groove on the outside of its boss, and is bolted down to the framing.

The advantages which, as we have seen, result from making power-lathes 'self-acting' are almost equally great when the same principle is applied to drilling machines. With the screw-feeding arrangement above described, it is simply necessary to impart to the hand-wheel a continuous slow motion, derived from some neighbouring moving part, to cause the drill to cut with perfect uniformity, instead of at one moment making little or no progress, and at the next having its strength unduly taxed through the inconstant attention of a workman. In the *Wall drill* (Fig. 204) the mode in which this is usually effected can be seen. Running loose upon the vertical shaft of the hand-wheel (H) is a worm-wheel (W), which is constantly being driven by an endless screw fixed upon a light horizontal shaft (S); this shaft being connected with the horizontal driving-shaft by a short belt passing over a pair of small speed-pulleys. Keyed upon the vertical shaft is a ratchet-wheel (R), which can at any moment be made to revolve with the worm-wheel (W) by means of a pawl (P) carried by the latter on its upper surface. On releasing the pawl, therefore, the drill can be raised or lowered by turning the hand-wheel (H); and on

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causing it to engage with the ratchet-wheel, the self-acting feed is brought into play, its amount being capable of being regulated by shifting the strap on the speed-pulleys.

Several other kinds of self-acting feed have been devised. One, invented by Sir J. Whitworth, is an expedient of considerable elegance, which Fig. 205 will serve to explain. Upon the upper part of the drill-spindle—which in

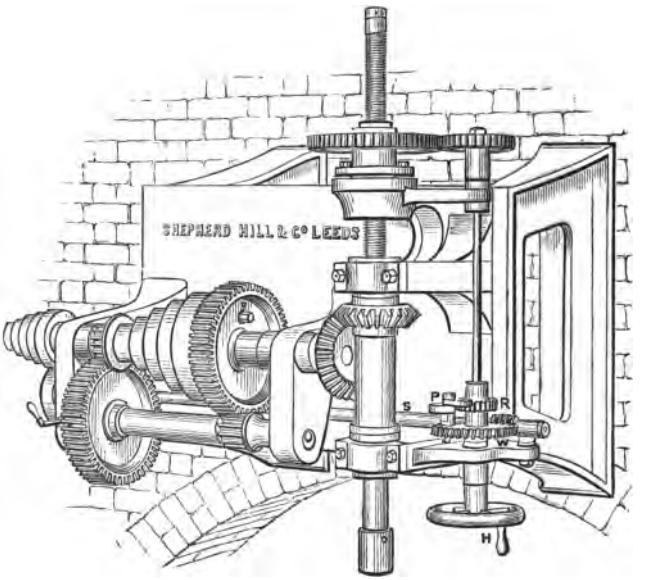

FIG. 204.—Double-Geared Wall Drilling-Machine.

this case is in one piece throughout its length—a screw-thread of moderate coarseness is cut, the somewhat complicated joint between the screw and the spindle shown in Fig. 203 being thus rendered unnecessary. If a fixed nut were attached to the upper part of the framing, this screw would provide the drill with a self-acting feed ; but it would have to be always exactly equal to the pitch of the screw,

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and could therefore never be altered. So, instead of letting it run through a fixed nut, it is made to pass between two worm-wheels, which, whenever the vertical motion of the spindle is arrested, themselves revolve in opposite directions. (One only of these worm-wheels can be seen in the engraving.) Their revolution, however, can be either wholly or partially checked by turning a handle, which works a right- and left-handed screw, and so draws together two clips (C C). These clips embrace a pair of friction-wheels (F F), keyed upon the short shafts which carry the worm-wheels, one of the shafts also having upon it a hand-wheel, which is not shown in the figure. When the friction wheels are so tightly clipped that they cannot revolve at all, they have the same effect as a fixed nut, and the feed is equal to the pitch of the screw; but for each diminution in the tightness of the clips the pressure upon the drill is reduced, and an increased motion is given to the worm- and friction-wheels. By loosening the clips and turning a hand-wheel, the drill-spindle (which is provided with a counterpoise to keep it from falling by its own weight) can be quickly raised or lowered.

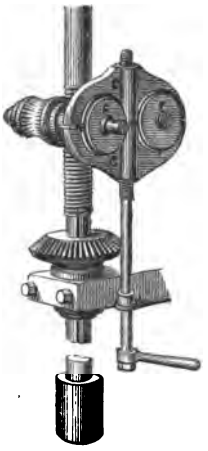

FIG. 205.—Whitworth's Drill-Feed.

Another method of obtaining a continuous feed motion, the invention of Mr. Bodmer, of Manchester, should be mentioned on account of its ingenuity, though it has never come into general use, owing probably to the impossibility of varying the rate of feed. The working parts of it are represented in Fig. 206. The drill-spindle—like the previous one—has a long thread cut upon the upper part of it, and screws into the boss of a spur-wheel, which thus forms a nut, which can itself be made to revolve. If both the spindle and the nut are driven at the same rate, the

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drill of course receives no feed motion. But by driving them in the direction indicated by the arrow, and giving them slightly different speeds, the spindle is slowly and continuously unscrewed; the amount of its descent (or feed) during each revolution depending upon the excess of its speed over that of the nut. Thus if, during each turn of the spindle, the nut passes through only three-quarters of a revolution, the feed will be equal to a quarter of the pitch of the screw.

Another kind of continuous feed, which is more extensively used for large drilling machines than any of the preceding ones, is on much the same principle as the rack-traversing motion in self-acting lathes. The drill-spindle is made in two parts, the lower, which carries the drill, being free to revolve independently of the upper, to which it is attached by a joint resembling that employed for connecting together the screw and the spindle in the screw-feed machines. In the circular pillar drilling machine (Fig. 207), the gearing for this *rack-feed*, as it is called, can be clearly seen, the teeth of the rack appearing on the right-hand side of the upper part of the drill-spindle. But in order to render this kind of feed self-acting, the driving speed must be reduced to a much greater extent than is necessary in the case of the screw-feed. This is effected by introducing a second worm-wheel for communicating the motion to the pinion which gears into the rack, in addition to the lower one, which is placed above the hand-wheel. The latter receives its motion from the smaller pair of speed-pulleys, by which the rate of feed can be varied; this portion of the arrangement exactly resembling that already shown in Fig. 204.

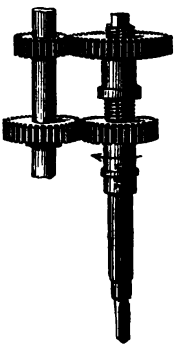

FIG. 206.—Bodmer's Drill-Feed.

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In addition to the feeding apparatus of drilling machines, much ingenuity has been expended in devising convenient forms of support for the work upon which they have to operate. One method—and the simplest one—is to extend the foot of the frame of the machine to a considerable distance, so as to make it form a flat *base-plate.* T-grooves for the reception of the heads of holding-down bolts being cast in this plate, and its surface being planed, it forms a very efficient support for articles of moderate size, of which the height does not exceed the distance between the point of the drill and the surface of the base-plate; for when a fixed base-plate is immediately under the spindle in any drilling machine, it of course sets a rigid limit to the height of the work which can be admitted. An example of a base-plate will be found in the engraving of the radial drilling machine (Fig. 209). Being of large size, it is cast in a separate piece from the framing; and, owing to the horizontal movement of the drill-spindle, the height of the work is not in this case limited by it.

Nor is this limit in point of height the only disadvantage of a fixed base-plate. Being kept as low as possible for the reception of large articles, it becomes a very inconvenient supporter of small ones. For these a *table,* adjustable as to height, is much better adapted. In its simplest form, it consists of a rectangular plate, planed and provided with T-grooves, which can be raised or lowered by a rack and pinion—the latter driven by a worm and worm-wheel, or in any other convenient way. But in this case the work must be perfectly correctly placed as to its horizontal position before it is bolted down to the table; and in drilling a series of holes, it must be set free, and be again adjusted for each one of the series. To obviate this, Sir J. Whitworth introduced his *compound table*—giving to the ordinary table a horizontal motion, on the principle of the slide-rest, in one direction, and, in addition, hanging it at a point near the vertical portion of the framing, so as to enable it to be swung horizontally in

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the other. The hinge also made it possible to swing the table entirely out of the way when the work was of sufficient height to be supported on a base-plate.

Various modifications of this are now in use, under the name of *swing tables*, the advantages of the arrangement for small work being universally recognised. For machines of comparatively small size, that shown in Fig. 202 leaves, perhaps, nothing to be desired. The table, which is circular, and is free to revolve round its axis, is supported by an arm, which can itself revolve round the vertical pillar of the machine. By combining these two motions, every part of the table can be easily brought under the drill, so that any piece of work of moderate size fixed upon it (for which purpose it has a series of slots, like the face-plate of a lathe) need not be unfastened till all the vertical holes which have to be drilled in it have been completed. In this case no vertical adjustment is provided, the table being placed at a convenient height for holding moderately small articles, and both table and arm being swung completely out of the way of any large ones. There being no base-plate, there is no particular limit to the height of the work which can be operated upon, a pit being occasionally sunk at the foot of the machine for the reception of long pipes, &c.

In larger machines—for the tables of which a vertical adjustment is important—the following arrangement is sometimes used, and it is an expedient of considerable ingenuity: The pillar by which the table is carried is converted into a 'circular rack,' by turning upon it a series of grooves. Into these grooves gears a pinion, just as it would gear into an ordinary rack—with this difference only, that whereas its teeth would engage with an ordinary rack only when the arm of the table in which it is fixed was on one side of the pillar, with the circular rack it can do so equally well on all sides. This enables the table to be raised or lowered, whilst at the same time it is slewed round to any required extent—providing it, in fact, with an efficient vertical adjustment,

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without in any way interfering with the horizontal ones just described.

Another way of effecting this, which admits of a plain

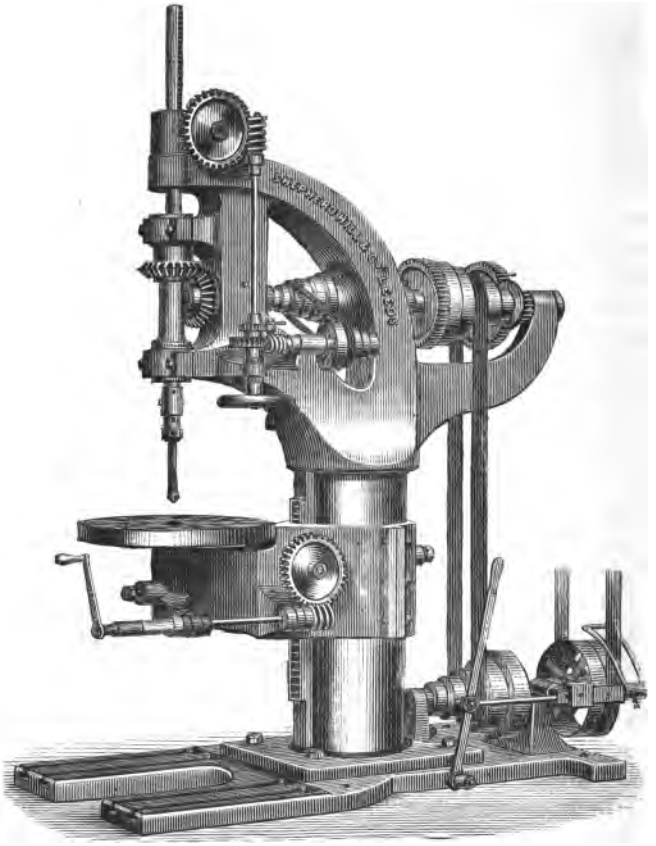

FIG. 207.—Double-geared Pillar Drilling Machine.

pillar being substituted for the circular rack above mentioned, is shown in the *Circular Pillar Drilling Machine* (Fig. 207). The arm on which the table is supported em-

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braces not only the pillar, but also an ordinary straight rack, which it carries round with it to any side of the pillar to which it may be swung. The worm and worm-wheel, which enable the height of the table to be adjusted by hand, may be clearly seen in the engraving.

With reference to the methods of fixing work upon the tables or base-plates of drilling machines, the reader who is familiar with the use of the face-plate of the turning-lathe will at once recognise the object of the slots with which the circular tables in Figs. 202 and 207 are provided. Any article which has vertical bolt-holes, horizontal flanges, or which is itself of no great height, can be secured by passing either plain or hook-bolts through the slots in the table; or clamps resembling those for the lathe face-plate (shown in Fig. 128) can be used when necessary. And upon rectangular tables or base-plates pieces of work can be secured in a similar manner, by means of their T grooves, into any part of which holding-down bolts can be inserted. But in most cases the weight of the work is sufficient to steady it, and to prevent its revolving with the drill; and if it manifests any disposition to move, the workman is generally able to steady it with his hand, so that it is unnecessary to secure it with bolts or otherwise. Large plates, &c., which cannot rest wholly upon the table, require of course extraneous support; but the shortness of the time occupied in drilling any moderate-sized hole generally makes it preferable to hold them by hand rather than to have recourse to any mechanical means of fixing them.

For steadying small pieces, especially such as have not a firm basis of their own—as, for instance, in drilling a hole transversely to the axis of any cylindrical work of small diameter—a *vice-chuck*, like Fig. 208, is a convenient addition to a drilling machine. The engraving sufficiently explains it—the slots in the base being for the purpose of bolting it down to the table, and the lever (which is moveable) for opening or closing up the jaws by means of the internal

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screw. The centres upon which the jaws are hinged should, however, be noticed, as their position, well above the point at which each jaw transmits its pressure to the work, conduces much to the steadiness of any article within its grasp, and prevents it from 'lifting.'

For holding articles whose form precludes their being bolted down upon a horizontal surface, but which can be attached to a vertical one, an *angle-chuck* is generally supplied with vertical drilling machines. It consists, like the lathe-chuck of the same name, of a short bar of L-, or angle-iron, planed on its outer faces. Both its horizontal and its vertical portions contain slots for the reception of bolts,—in the one case for fixing the chuck to the table or base-plate

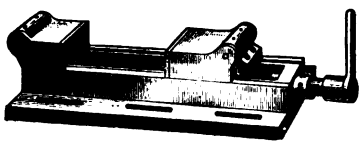

FIG. 208.—Vice-Chuck.

of the machine, and in the other for attaching the work to the chuck.

When a drilling machine is required for operating upon large pieces of work only, a wall-drill—of one example of which an engraving has already been given (Fig. 204), and in which both base-plate and table are dispensed with—is perhaps the most convenient form of all. Its framing is then so made that it can be fixed to the wall of the workshop, and the whole of it is kept above the drill, so as to be quite clear of any work placed underneath it. Moreover, by turning an arch in the wall, and fixing the machine at its crown, the clear space below the framing can be still farther extended, so that a boiler or any other large object can be operated upon with perfect facility.

'Double-gearing' has been so fully described in connection with the lathe, that it is unnecessary to do more than

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to refer to it here. Both its object—that of obtaining greatly increased power by a corresponding sacrifice of speed—and the gearing by which this is effected, are in general perfectly similar, whether the work is to be performed in a power-lathe or in a drilling machine. The latter, when intended for drilling holes of more than about two inches in diameter, should always be provided with it.

One other variety of vertical drilling machine should not be passed over, inasmuch as it affords facilities for drilling vertical holes in large or ponderous articles by adopting the principle of adjusting the drill over the work instead of arranging the work under the drill. In this respect the *Radial Drilling Machine* (Fig. 209) differs materially from the machines for drilling which we have thus far been considering. The way in which this power of adjustment is obtained—as will be understood from the engraving—consists in supporting the drill-spindle, together with the gearing for driving and feeding it, upon a slide or carriage which can travel horizontally along a radial arm, the arm itself being moveable about a vertical hinge near its point of junction with the fixed pillar of the framing. By combining the travel of the slide with the circular motion of the arm, the drill can be brought not only over any part of the base-plate of the machine, but even to a considerable distance beyond its limits on either side. The height of the arm can also be adjusted, it being for that purpose hinged to a long vertical slide, instead of directly to the framing.

But these advantages are not obtained without considerable sacrifice of simplicity in the working parts, as must be evident when we consider that the driving power has to be transmitted first to the radial arm, whose height and direction are variable, and from it to the drill-spindle, of which the position and height are also variable. Means must be provided too for raising or lowering the arm, and for regulating the traverse of its slide, without interfering with the self-acting feed-motion of the drill-spindle. The

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manner in which these requirements are satisfied will probably be self-evident on studying the figure, in which the reader who has accompanied us thus far in the subject of drilling machinery will not find much difficulty in tracing out for himself the course of the power from the driving-

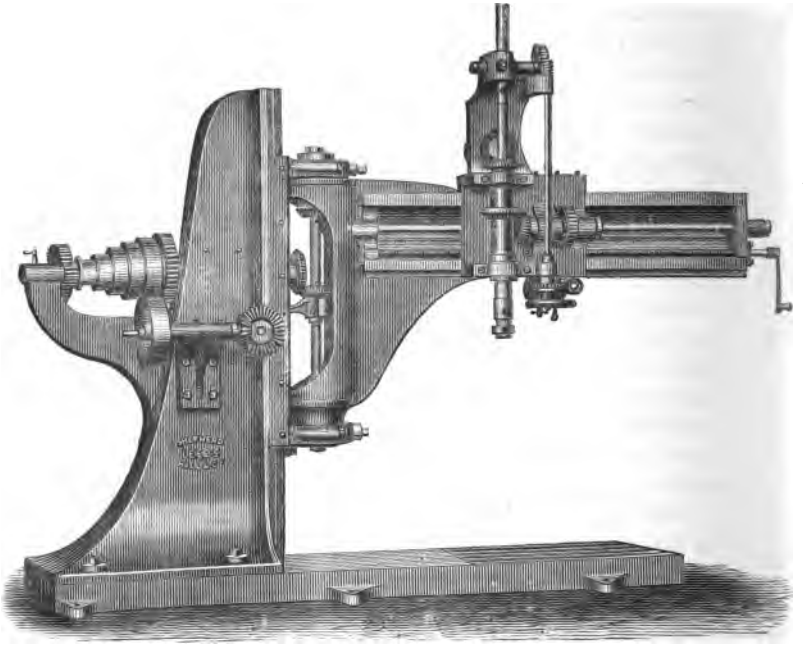

FIG. 209.—Radial Drilling Machine.

pulleys to the drill, nor in understanding what may be called the subsidiary parts—for feeding, adjusting, &c.

One fact should be borne in mind, for it greatly simplifies this task, not only in machines of comparatively few parts, like the present one, but in most others, however complicated they may at first sight appear. It is this : that in

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all properly designed machinery the strength of the working parts is proportioned to the strains they have to bear; so that by observing their strength a good idea may be obtained as to the amount of power they are intended to transmit. Toothed wheels, shafts, &c., will thus be found to a great extent to tell their own story, the thickness of the teeth of the former and the breadth of their faces, and the diameter and length of the bearings of the latter, being frequently most valuable guides in assigning to each their respective duties. Examining, for instance, in this way the various working parts of Fig. 209—keeping in mind of course the main object of the machine, which is in this case to convey the power from the driving-pulleys to the drill-spindle without any great alteration of speed (except through the agency of the double gearing)—a single glance assures us that the horizontal shaft running along the radial arm, and also the vertical shaft between the trunnions on which the arm is hinged, are for the purpose of transmitting this power, since they, and also the drill-spindle, are approximately of the same diameter. An inspection of the gearing by which they are connected confirms this impression.

The vertical shaft is driven from the double-geared pulleys by a pair of strong bevil-wheels—which are clearly seen near the centre of the hinge of the radial arm—the rise and fall of the arm being provided for by grooving the vertical shaft and fixing a feather in the boss of its bevil-wheel, this wheel being supported by a bracket projecting from the fixed part of the framing. Similar bevil-wheels connect the vertical with the horizontal shaft (one of these is partly seen in the figure just below the upper trunnion of the radial arm), which also is grooved throughout its length on account of the traverse of the slide, a pinion in this case at the back of the slide being carried with it to any part of the arm to which it may be moved, and a feather in the boss of the pinion remaining constantly in the groove of the shaft, so as to receive its motion. This pinion cannot be seen in the

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engraving, but the spur-wheel in front of the slide which gears into it shows us at once by the width of its face (which is almost equal to that of the spur-wheels of the double gearing) that it transmits the driving power to the drill, and has nothing to do with its adjustment or feed. One other pair of bevil-wheels gives revolution to the drill-spindle—*which* of the two pair with which it is furnished the reader will have no hesitation in determining for himself on the principles above recommended. The others convey the minute proportion of the driving power which is required to make the feed self-acting; a pair of small conical pulleys at the back of the radial arm giving the requisite control over its speed. These, however, and the 'rack-feed' generally, have already been noticed; so we will here only call attention to the smallness of the diameter of the vertical shaft, which performs the very light duty of connecting the lower worm-wheel with the upper worm. Still one other pair of bevil-wheels remains, namely, those in front of the standard of the framing. They are for the purpose of raising or lowering the radial arm, together with the slide, gearing, &c., which it carries; the combined weight of which renders it necessary to give considerable strength to the teeth of the wheels by which this is effected. So that in this case there may at first sight be some doubt as to their use, although a small amount of consideration (with which the application of what has been said above must always be accompanied) soon points out the necessity for their somewhat exceptional strength. In this adjustment a hand-wheel, worm, and worm-wheel are sometimes substituted for the bevil-wheels and pulley shown in the engraving, the circular motion being in each case converted into a vertical one by means of a pinion gearing into a rack which is fixed to the slide upon which the radial arm is hinged.

The bases of radial drilling machines are occasionally made of sufficient height to enable their vertical sides to be utilised in holding articles which can be more conveniently

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affixed to a vertical than to a horizontal surface. When this is the case the base assumes the form of a large rectangular box, with horizontal T-grooves cast upon its sides and ends.

The following particulars of the vertical drilling machines figured above will serve as a guide in stating the capabilities of others of the same kind.

The single-geared machine (Fig. 202) is capable of drilling holes up to $1\frac{1}{2}$-inch in diameter, to a depth of 10 inches, the distance of the centre of the hole from the edge of the work being limited to one foot.

The wall-drill, of which an outline is given in Fig. 204, has, of course, no limit as to the position of the hole which it can drill, and, being double geared, its diameter can be as much as 6 inches, the travel of the drill-spindle, which determines its depth, being 14 inches.

The powerful double-geared 'circular pillar' machine (Fig. 207) can, like the preceding one, drill holes up to 6 inches in diameter, their greatest distance from the edge of the work being 15 inches. It can admit articles 3 feet 6 inches high.

The radial drilling machine (Fig. 209) is also adapted for drilling holes up to 6 inches in diameter, the travel of the spindle being 13 inches. Its arm has 18 inches of vertical adjustment, and can be swung round upon its axis through something more than a semicircle. The travel of the slide upon the arm enables the drill to be placed at any distance between 2 feet 6 inches and 6 feet from the centre of its trunnions.

The drills used with these and similar machines were formerly almost exclusively of the type shown in Fig. 210; and where the sides are parallel for a short distance from the cutting end, so that they afford a certain amount of guidance, fairly straight and clean holes can be made with them. But the thickness of the point, and the disadvantageous position of the front face of the cutting portion, which tend to render the action slow and imperfect, even

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with small drills, become seriously objectionable in the case of large ones. By forming 'lips,' however, in the manner shown in the sketch (Fig. 211), considerable improvement in both of these particulars can be effected. A half-inch lipped drill when working well should perforate a wrought-iron plate one inch thick in about half a minute, and an inch drill in about one minute.

FIG. 210.—Plain Drills.

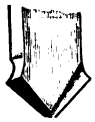

FIG. 211.
Lipped Drill.

FIG. 212.—Twist Drills.

Twist drills have of late years come much into use for drilling holes of large as well as small diameter, and they fully deserve the preference which is now very generally accorded to them. Two such drills, with tapered shanks, suitable for use with drilling machines, are represented in Fig. 212. They are obtainable up to 3 inches in diameter,

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a full set consisting of 53 drills, ranging from this size down to $\frac{1}{4}$ of an inch; but the large ones are costly. Owing to the large extent of their cylindrical 'guiding' surfaces the holes which they produce are superior, both in straightness and smoothness, to those made with drills of the old pattern. The facility with which they can be sharpened without interfering with the original diameter is also much in their favour. The grinding of the extremity, however (which is all that is necessary in sharpening), requires to be done with considerable accuracy, and as equally as possible on each side of the point, to assist in which the drills are now marked with a central 'grinding-line' at the bottom of each spiral groove. Various emery drill-grinding machines have special provision for attaining this end, and at the same time preserving the original angles of the cutting edges, and their use is no doubt advantageous wherever much drilling is required.

When the diameter of a hole that is to be drilled is considerable, it is generally preferable first to drill a smaller but accurately placed 'leading-hole,' and afterwards to enlarge this by following it up with a drill of the required size. *Pin-drills*, made on the same principle as the Plug-Bit (Fig. 56), and used in this way, give good results, provided that the size of the leading-hole is such that it just fits the pin. So, also, do such tools as the *Recessing Bit* (Fig. 213), and the iron *Boring Bar* with a loose steel cutter

FIG. 213.
Recessing Bit.

FIG. 214.
Boring Bar.

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keyed into it (Fig. 214), the necessary guidance in all these cases being afforded by the leading and not by the finished hole. The special object of the Recessing Bit is for enlarging the ends of screw-holes, so as to admit the heads of 'cheese-headed' screws, but it is introduced here as a suggestive form, easily made, and adaptable to various purposes.

To the subject of Boring Bars we shall return a few pages further on.

But before quitting the subject of drilling we must mention the so-called *Multiple Drilling Machines.* Whatever may have been the purpose for which they were originally devised, their first introduction on a large scale was due to Messrs. Cochrane of Dudley, who employed them in the manufacture of wrought-iron girders. For such purposes—in which it is necessary to drill very large numbers of rivet-holes with rapidity, and to place the drills with such accuracy as to ensure perfect correspondence between the holes—they offer very great advantages. Fig. 215 shows the end standards, with a portion of the horizontal girder by which the drill-spindles are carried in a machine of this kind, by which upwards of forty holes can be drilled simultaneously. A section through the girder is given to an enlarged scale in Fig. 216. The standards are placed at a sufficient distance apart to admit between them the longest plate which has to be operated upon, so that the length of the machine varies according to the purpose for which it is intended. In any case a planed table for the support of the plate extends under the whole range of the drills, hydraulic cylinders or other mechanical means being provided for slowly raising this table, and thus bringing the work gradually up to the drills, instead of complicating the spindles by giving them any vertical feed-motion. One hydraulic cylinder only appears in our engraving, the second, together with about three-fourths of the number of drill-spindles with which the machine is provided, having been necessarily

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omitted. To enable the holes in the plate to be drilled at any required points, each spindle is supported in an independent frame, which can be fixed at any part of the girder

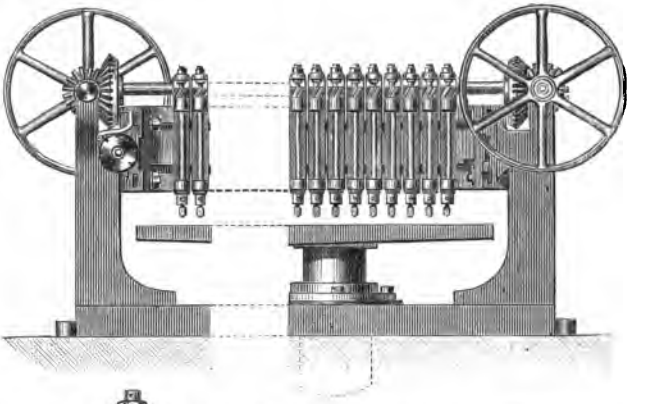

FIG. 215.—Multiple Drilling Machine. Part Elevation.

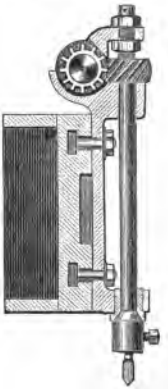

FIG. 216.
Section enlarged.

by two ordinary screw-bolts, horizontal T-grooves being cast in the girder to receive their heads. The drills when arranged are driven simultaneously from a horizontal shaft running along the top of the girder, connection being established between them by an unusual and ingenious form of helical gearing, which for such a case as this possesses an advantage over ordinary bevil-wheels. It consists in placing on each drill-spindle, and also on the driving shaft opposite to it, a short length of a many-threaded screw. These, which are precisely similar to one another, and in appearance resemble small spur-wheels with inclined teeth, are capable of working together (by sliding instead of rolling contact) when their axes are at right angles to each

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other. Being of much smaller size than bevil-wheels of equal strength, they allow the spindles to be placed much closer together than would be possible if they were driven in the usual way with bevil-gearing. Indeed, by driving the alternate spindles from separate shafts placed one above the other, they can be so arranged as to drill holes of which the centres are only $2\frac{1}{2}$ inches apart.

With none of the foregoing machines is it possible to drill holes of other than circular section, although for some purposes—such as in the expansion joints of iron structures, and possibly also for obtaining increased sectional area of rivet in rivetted plates—it is desirable to give them a more or less elongated section. With punching machines, as we shall see presently, holes of almost any required form can be produced, but for highly finished work they are inadmissible, and machines have, therefore, been devised with which elongated holes (as in Fig. 208) can be drilled at a single operation, the proportions between their length and widths being variable within very considerable limits. This process is known as *Slot Drilling*. Fig. 217 shows an example of it, and one of several varieties of machine for doing it is given in Fig. 218. It will be seen that the drill-spindle is mounted on a carriage which is supported by a horizontal slide, much in the same manner as in the radial machine (Fig. 209). The carriage, however, instead of being adjusted once for all, as in that case, continually receives a slow backward and forward motion along the slide to an extent which depends upon the amount by which the length of the hole is to exceed its width. This motion, proceeding simultaneously with the rotation of the drill, produces a hole of the desired form, which may be carried either entirely or only partially through the work. In the engraving the 'cross-head' of a steam-engine is shown in position for having a cotter-hole drilled in

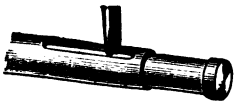

FIG. 217.—Slot Drilling.

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this manner, the table on which it is supported being capable of being adjusted as to height, or being entirely removed, so that no vertical adjustment is required for the slide. The movement is given to the carriage by connecting it at the

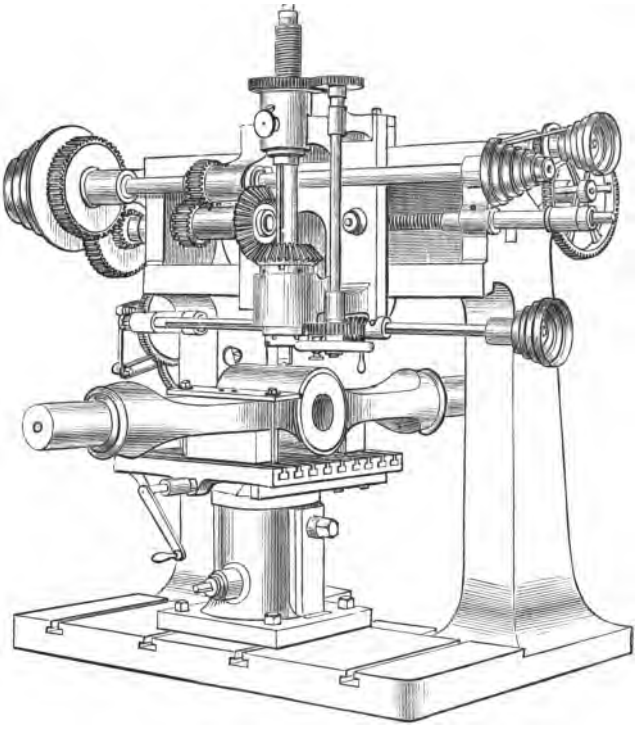

FIG. 218.—Slot-Drilling Machine.

back with a stud which projects from the face of a revolving disc, the extent of the motion being determined by the distance from the centre of the disc at which the stud is fixed. In order to overcome the irregularity with which the carriage would move at the different parts of its traverse

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if the disc were to revolve at a uniform rate, the pinion by which it is driven is made eccentric and the disc itself elliptical; by which arrangement the lateral movement of the carriage, and therefore of the drill which it supports, is rendered everywhere nearly uniform.

For the combined horizontal and vertical cut thus obtained, the usual pointed drills cannot be employed. It has been found, indeed, that the best results are obtained by using a tool from which the central part of the cutting edge has been entirely removed. The *Forked Drills* shown in Fig. 219 are examples of slotting tools of this kind, one of them being made from solid steel by forging and grinding, and the other by fixing loose cutters in a permanent stem. As roughing tools, forked drills answer their purpose well, being rapid in their action. But when smoothness of surface is required, they must either be followed by some kind of finishing drill, or they must be abandoned in favour of some other form,—such as *Square-ended Drills*, in which a small portion only is removed from the centre, as shown in Fig. 220.

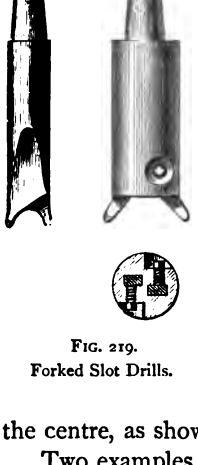

FIG. 219.
Forked Slot Drills.

Two examples of *Rose Drills* for finishing are given in Fig. 221, the cutter of one of them being formed in a separate piece from the stem, so that other sizes can be substituted for it. The stems of slotting drills, whatever their form may be, and also the spindles which carry them, must possess much greater strength than is required for ordinary drilling, on account of the side-strain to which they are subjected.

The *Slot-drilling machine*, Fig. 218, can take in objects of any length, provided that the height does not exceed

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3 feet, and slotted holes up to 13 inches by $4\frac{1}{2}$ inches can be drilled in them to a depth of $11\frac{1}{2}$ inches. Various other forms are also made, some of which are provided with duplicate spindles, tables, &c., so that two slotted holes or grooves can be drilled at the same time either in one piece or in two separate pieces of work. For the use of these machines is by no means confined to the drilling of holes for such purposes as we have mentioned. Key-beds and many similar recesses may be cut with them in positions upon which other machine tools could not be brought to bear, and their performance is such that no after-treatment with the file or other tool is required. On a similar principle—the motion, however, being given to the work instead of the tools—an entire series of slotted holes could be easily drilled at once if required.

FIG. 220.
Square-ended Slot Drill.

In passing on now to *Boring*, which implies the use of some description of *Boring Bar*, we may mention that one very simple method of performing the operation consists in fixing between the centres of a lathe a plain iron bar, such as Fig. 214, with one or more transverse slots somewhere near its centre. Into each slot a cutter, either single or double-ended, is keyed ; the article to be bored—which must have an opening through it of sufficient size to admit the bar—being attached to the saddle of the slide-rest, the movement of which along the bed of the lathe feeds the work continuously up to the tool. The length of the bar must be about double that of the cylinder or other article to be bored, and its diameter must be sufficient to enable it to support

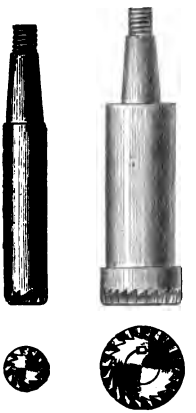

FIG. 221.
Rose Slot Drills.

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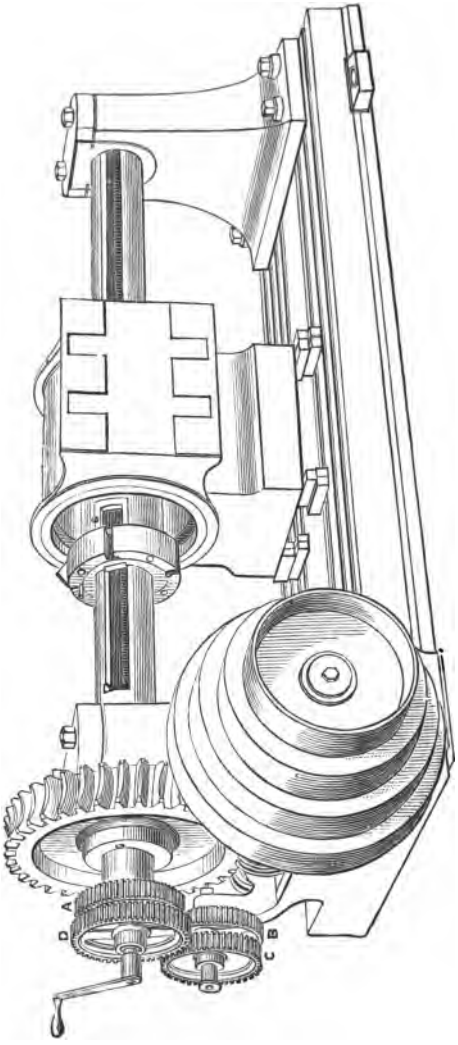

FIG. 222.—Horizontal Boring Machine.

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the cutter rigidly, and at no great distance from its cutting edge.

But in *Boring Machines* the opposite method is generally preferred, the work being kept stationary and the feed-motion given to the cutter or cutters. The usual arrangement is to mount several of these round the circumference of a *Cutter-Block* capable of sliding along the whole length of the boring-bar, which need not then greatly exceed the length of the boring for which it is to be used.

Fig. 222 shows a *Horizontal Boring Machine* with a locomotive engine cylinder in position for being bored out. In this case the cutter-block has slots for receiving four cutters, and its sliding movement or 'feed' is regulated by the long screw within the bar. Thus it is merely necessary to drive the bar and the screw at slightly different rates of speed in order to obtain a continuous feed-motion. Different makers accomplish this in different ways, the arrangement shown in the engraving being as follows :—

The screw, which is here concentric with the bar, is carried beyond it at the driving end, and through the centre of a spur-wheel (A) which is keyed upon the bar. Upon the end of the screw a second spur-wheel (D) is fixed, its diameter being greater than that of the first by an amount which depends upon the speed which is to be given to the screw. Into these gear two wheels (B and C), of which the diameters differ to the same extent as those of A and D. Since B and C are so connected that one cannot rotate without the other, their effect, when the bar is in motion, is to oblige D to revolve slightly more slowly than A, thus imparting to the screw to which D is attached a slow revolution, independent of that of the bar. Different rates of speed may be obtained by substituting differently proportioned wheels for C and D.

Other modes besides the large worm and worm-wheel in Fig. 222 are employed for driving the bars of boring machines, but some form of screw feed is almost invariably adopted,

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uniformity and steadiness in this being of great importance.

The high degree of accuracy now reached in the boring of steam cylinders has led to the discovery of previously unsuspected sources of error in work of this class. It has been found, for instance, that the distortion of a large cast-iron cylinder due to its own weight only, when it is laid horizontally and bored truly in that position, is sufficient to render its form incorrect when it is placed vertically, and *vice versâ*, so that large cylinders must be bored in the position which they are to occupy when in use.

The diagram, Fig. 223, shows two views of a *Cutter* mounted in the sliding head of a vertical boring-bar. In

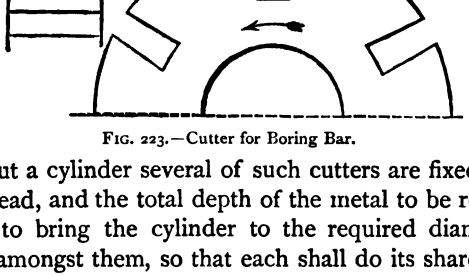

FIG. 223.—Cutter for Boring Bar.

boring out a cylinder several of such cutters are fixed in the boring-head, and the total depth of the metal to be removed in order to bring the cylinder to the required diameter is divided amongst them, so that each shall do its share of the work. The last cutter of the series is very carefully finished on an oilstone, and is so adjusted that it takes off only a minute quantity of metal from the surface of the cylinder, which it thus leaves smooth and bright. By this means a cylinder of even 120 inches in diameter may be bored practically correct. The only difference of form between the roughing cutters and the finishing cutter is that the front face of the latter is made more nearly radial, so that it may be said to scrape and burnish the metal surface but scarcely to cut it.

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Cylinders which can only be attacked from one end necessitate the use of boring-bars on a different principle. In their case the cutters must obtain the requisite guidance from the bore itself,—just as a rimer or a screw-tap is kept to its true course,—and they can be carried by a simple fixed head at the end of the bar. This method was very early used, and has been carried to great perfection in connection with gun-boring. It will be readily understood from the engraving below (Fig. 224), which represents the head of a *Gun-Boring Bar* for taking a minute final cut from the bore of heavy ordnance. The cutters (A A) are six in number, and they are firmly secured to the head, being carefully adjusted as to distance from the axis of the bar by packing them at the back with very thin paper. As may be observed, they are

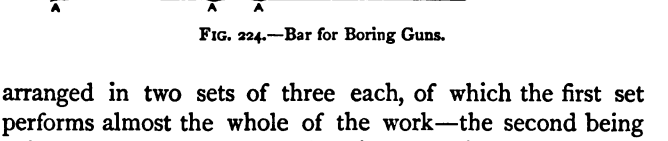

FIG. 224.—Bar for Boring Guns.

arranged in two sets of three each, of which the first set performs almost the whole of the work—the second being chiefly added as a safeguard against error in the size of the bore on account of wear of the short cutting edges, which takes place to a small but an appreciable extent in the course of even a single boring. Following the cutters is a series of six guide bars (B B B) arranged spirally, which are made exactly to fit the bore. Provided that the length of these is sufficient, and their fit perfect, it is evident that the cutters cannot advance except in a straight line ; so that in order to ensure the direction of the bore being correct throughout, it is only necessary for it to be correctly started. Moreover, the true circular form is effectually secured to it by the spiral arrangement of the guiding surfaces, which prevents its having any tendency to become polygonal.

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The power and efficiency of modern gun-boring machinery may be appreciated from the fact that with that now used in the Royal Gun Factories at Woolwich a hole 10 inches in diameter and 25 feet deep can be bored in solid steel at a single operation, and bores have been carried nearly to this depth with a variation of less than one-hundredth of an inch in the diameter.

An improved boring tool recently introduced there by the superintendent, Colonel Maitland, R.A. (to whose courtesy we are indebted for the hitherto unpublished drawing and description of it here given), is especially interesting, both as a suggestive form of special tool, and as an

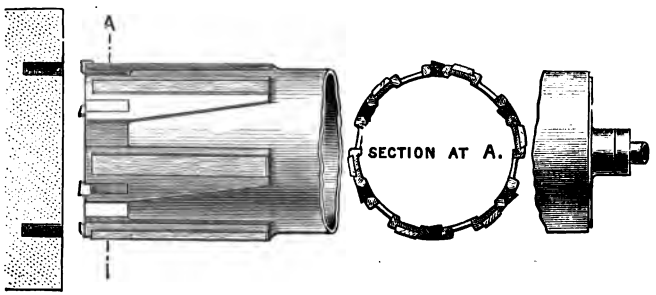

FIG. 225.—Trepanning Bar.

instance of the economy which may be the result of a judicious departure from established practice, when occasion demands it.

Instead of uselessly expending power, and frittering away a very costly material by reducing to shavings the mass of metal which must be removed in the process of forming the inner portion of a gun by boring out a steel ingot, Colonel Maitland takes out a solid core by means of the *Trepanning Bar*, Fig. 225. The head or working end of this carries a series of cutters—six or more in number, according to the diameter of the head—arranged to act alternately on the inner and the outer halves of its annular cut, hard wood

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'burnishers' giving the necessary guidance and steadiness. In the cross section in Fig. 225, the acting portion of each cutter is shown in black.

The removal of the shavings is effected with complete success by introducing a stream of soap and water, under pressure, through the pipe at the opposite end of the bar, which, as it can escape only by passing first through the longitudinal channels left for the purpose on the inside, and then through those on the outside of the head, keeps the working face constantly clear. With a tool of this kind, with an 11-inch head, solid steel has been bored at a rate of about 3 inches per hour to a depth of 25 feet, the diameter of the core being $9\frac{1}{2}$ inches. And these dimensions do not at all indicate the full capabilities of the system, which appears to be quite equal to meeting every demand which is likely to be made upon it.

Up to the present time (1883), the largest tool of this kind actually at work is a 14-inch bar with 10 cutters which bores at the rate of $2\frac{1}{4}$ inches per hour; but several others —up to 24-inch bars with 18 cutters—are being made, and still further extensions of the principle are in contemplation.

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CHAPTER VIII.

ON PLANING, SHAPING, AND SLOTTING MACHINERY.

THE modern *Planing Machine* is essentially a copying machine. It reduces a surface to flatness, or to a close approximation to flatness, by making upon it a series of parallel cuts with a tool which is generally more or less pointed. Each of these cuts is, as to direction, an exact copy of the movement of that portion of the machine by which the work is supported, or, in other words, of the slide which determines the nature of this movement; whilst the line in which each fresh cut follows the previous one is also a copy —in this case of the slide along which the tool receives its feed-motion. If both of these movements take place in straight lines—as they must whenever they result from the sliding of plane surfaces upon one another—every portion of the work upon which the extremity of the tool has been made to act lies in one and the same plane surface; but if either the one or the other of them be made to follow a circular path, it is evident that instead of a truly flat surface we shall obtain a curved one, with equal accuracy. We shall see in the course of the present chapter that this latter combination of movements, as well as the former, is turned to useful account in mechanical workshops.

A good example of an ordinary Planing Machine is given in Fig. 226. It consists essentially of a sliding table for supporting and giving a reciprocating motion to the work, together with suitable arrangements for fixing one or more planing tools above it and for providing them with an intermittent feed.

First let us examine the construction of the table, and the means adopted for imparting to it the necessary motion

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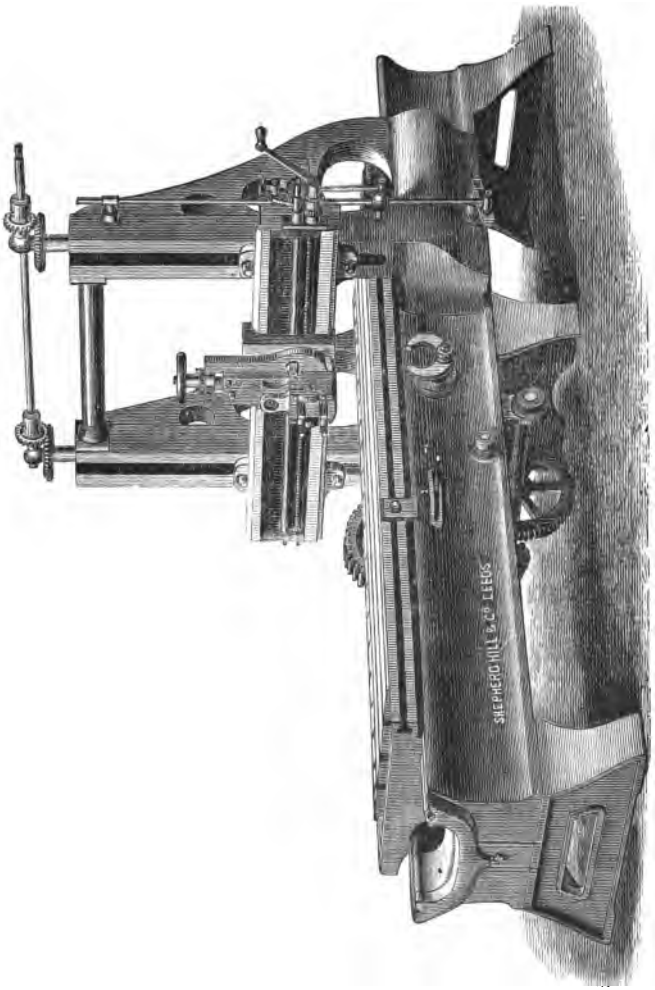

FIG. 226.—Planing Machine.

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along the bed. The two parallel beams or cheeks which form this bed, giving it some resemblance to a lathe bed, have upon their upper surfaces V-shaped grooves, made accurately parallel throughout the entire length of the machine, and truly plane as regards their sides. Corresponding projections, which are cast on the under side of the table and are also carefully worked up to a true surface, serve to convert the bed and the table together into a large slide, no other security besides the weight of the latter being necessary to keep it from leaving the grooves. The table, however, must not only be enabled, it must be compelled to slide backwards and forwards along the bed, and that both with sufficient force to cause the tool to take a cut from the surface of the work, and to a sufficiently variable distance for its motion always to correspond with the length of the portion which has to be planed. The usual method of effecting this is to fix a rack in the centre of the table on its under side, a pinion (of wrought iron) which gears into this being driven—through a train of wheels capable of sufficiently reducing the speed—by a belt and pulley in the ordinary way. Were it not for the necessity of constantly reversing the motion, all would be simple enough, but after each cut has been made the table must be brought back to the position whence it started; and since the tool cannot act when the work is moving away from its edge, it becomes an object to spend as little time as possible over the return stroke.

This has led to the introduction of various methods of obtaining a *quick return*, one of which will be intelligible from the accompanying diagram (Fig. 227), which shows the general arrangement of the wheels in the planing machine represented above. Their duties are threefold: first, to effect a sufficient reduction in the speed of the shafting from which the machine is driven; secondly, to convert the rotary motion thus reduced in speed into a forward horizontal one (the table as it appears in the figure being thus moved

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from left to right); and thirdly, to produce a similar backward movement at a less reduced speed. For the second of these—namely, the conversion of the circular into a rectilinear motion—the rack below the table, which has been already mentioned, provides. A short length of this is shown at R in the diagram, the wrought-iron pinion and the large spur-wheel, of which the upper portion can be seen in the general view of the machine, being represented by P and S respectively. Of the three pulleys and the remaining toothed wheels, those by which the forward stroke is given

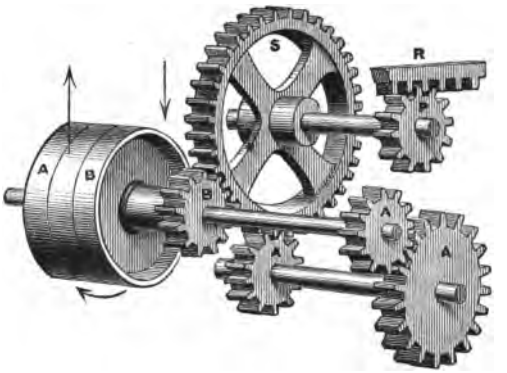

FIG. 227.—Quick-Return Gearing.

are marked A, and those for the return stroke B; the increased number of wheels in the former of these trains being for the purpose of sufficiently reducing the speed, which, as already pointed out, would be a positive disadvantage for the latter. The central pulley is 'idle,' that is to say, it runs loose upon the shaft, as also does the 'return' pulley which is marked B, but this last is inseparably connected with the pinion B. In order, therefore, to drive the table alternately backwards and forwards at these different speeds, it is only necessary to shift the strap from one of the outside pulleys

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to the other at proper intervals, the idle pulley between them allowing a short period of rest between the two motions. This can be done by merely moving to one side or the other the lever which projects from the bed near the centre of the machine, but by a simple arrangement, to the consideration of which we will now pass on, the table itself is made to change the position of the strap when it comes to the end of its traverse, whatever the length of that traverse may be.

Projecting from the bed of the machine near the lever just mentioned, two short curved arms may be perceived, of which the resemblance to a pair of *horns* has gained for them that appellation. They also appear in the diagram (Fig. 229), where they are marked H H′, in which the portion of the figure which lies to the left of them, taken in connection with the plan of the strap-shifting arrangement shown above it, will serve to explain their action with but little verbal description. It should be noticed, however, that the horns H H′ are not in one and the same vertical plane, H′ being placed in front of H by the amount of its own thickness. By providing the table, therefore, with two adjustable *stops*, one in the plane of each of the horns, and setting these at proper distances apart for reversing the motion at any required point, the short shaft to which the horns are attached is turned to a small extent alternately to one side and to the other, thereby moving the lever L, the sliding bar G, and the fork F, between the fingers of which the strap passes to the pulley. One only of the stops appears in either the perspective view or the diagram. In the latter it is marked J.

A planing machine, however, is required to be self-acting with regard to the feed of the tool as well as in respect of the traversing motion of the table, and, since the feed must be intermittent, this too can be conveniently derived from the movement of the horns by which the shifting of the strap is accomplished. But before turning our attention to the arrangement by which the feed is made

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self-acting, we must examine in some detail the construction of the apparatus by which the tool is supported.

A *Tool-holder* or tool-box, as it is sometimes called, is represented in Fig. 228. The cross-slide which carries it can be seen distinctly in the general view of the machine (Fig. 226), in which also should be noticed the bevil gearing at the top of the side standards, by which the cross-slide itself can be raised or lowered. The screws within the standards, upon the upper extremities of which one of each pair of these bevil-wheels is fixed, thus form a rough adjustment for the height of the tool. But for finally adjusting it, and for giving also a vertical feed to it when required, the tool-holder is furnished with a slide, the two halves of which are marked U and Y in the engraving. By turning the hand-wheel which is keyed upon the top of the vertical screw, V can be raised or lowered. The tool, however, is not attached directly to the moving half of the slide V. It is often desirable to incline it to a small extent either to one side or the other, for which purpose V has affixed to it a slewing-plate W, which is capable of being set to the required inclination, and being retained in that position by a bolt passing through a slotted hole in the upper portion of it. But even to these the tool is not directly attached. For it is found to be highly injurious to the cutting edge to keep it in contact with the work during the return stroke—an evil which is perfectly remedied by hinging the front plate (X), instead of connecting it rigidly with the slide. By this, therefore, the tool is carried.

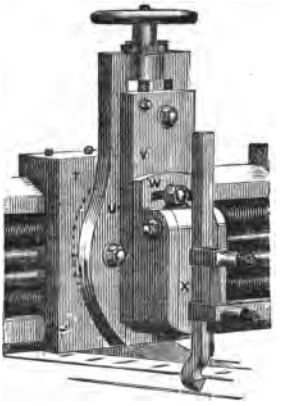

FIG. 228.—Tool-Holder.

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In addition to slewing the tool by means of the plate W, it is sometimes important to be able to give it an inclined or 'angular' feed instead of a vertical one. This is provided for by making the hinder portion of the slide (U) moveable laterally about a point somewhat below its centre, the bolts by which it is attached to the saddle T having the heads constantly in some part of a circular T-groove, so that U, and with it the entire front portion of the tool-holder, can be clamped by them at any desired inclination, the angle being indicated by graduations on the face of the saddle.

Let us now see how the feed-motion can be given, whether this slide be set vertically or inclined. In Fig. 226 two light shafts may be observed running from end to end of the cross-slide, and passing behind the saddle of the tool-holder. One of them (the lower one) has a screw-thread cut upon it, by which it drives the tool-box horizontally along the cross-slide in the ordinary way. But it is the other shaft which communicates motion to the parts which we have just been examining, and this has no screw-thread, but merely a longitudinal groove. Upon it is a small bevil-wheel with a feather in its boss, which by this means is made always to revolve with the shaft, although it can travel freely with the saddle to any part of the cross-slide. Gearing into it is a second bevil-wheel, and attached to this is a third, the horizontal axis upon which these last jointly revolve coinciding with that about which the front portion of the tool-box can be adjusted. One other bevil-wheel upon the lower end of the vertical screw establishes the connection between this and the grooved shaft, the screw of course moving the slide equally whether it receives its own motion through the hand-wheel at its upper, or through the bevil-wheel at its lower, extremity. The arrangement may seem to be complicated, but it appears to be the simplest which can be used for transmitting the motion between two shafts, of which the axes are in different planes, and which have also a variable inclination to one another. It enables either

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a vertical or an inclined (or 'angular') feed to be given to the tool with equal facility.

It now only remains for us to trace the motion to the shafts within the cross-slide, and to observe how its amount can be regulated so as to vary the feed of the tool. And by merely increasing the number of the parts the same arrange-

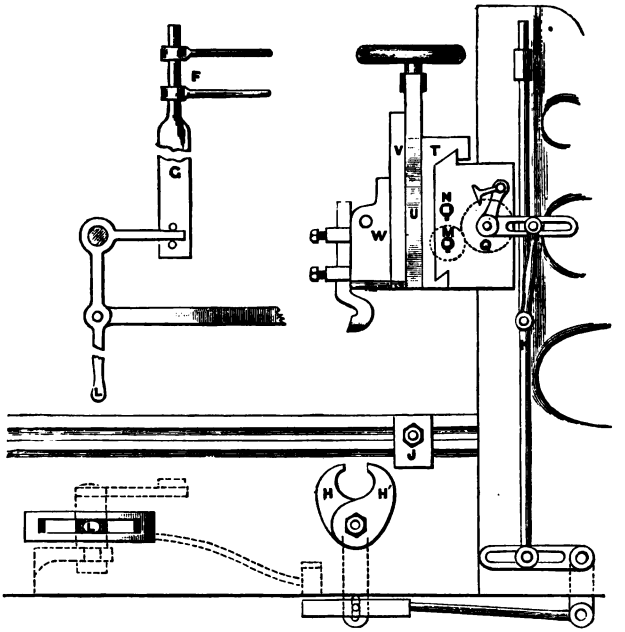

FIG. 229.—Diagram of Feed-motion and Reversing Gear.

ment can be made to serve when two tool-holders are attached to the cross-slide, which is generally the case in the larger sizes of planing machines. Two screwed shafts and two with grooves are then placed within the cross-slide, either pair being capable of being simultaneously set in action, so that feed-motions, similar both in amount and in

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direction, can be imparted to both the tools. In the portion of the cross-slide which appears in Fig. 228, this duplicate set of shafts may be observed, the machine to which it was attached having been provided with two tool-holders, although—in order to avoid complication—we have selected for the general view (Fig. 226) a smaller machine which has but one.

In the diagram, Fig. 229, is the side view of a cross-slide with a single tool-holder, of which the various parts are indicated by the same letters as in the perspective view already given (Fig. 228). The ends of the horizontal screw and grooved shaft appear at M and N respectively, and it is to one or the other of these that it is required to impart a small amount of rotation (in either direction) which must be capable of sufficient variation to make the feed of the tool either heavy or light. For this purpose a small spur-wheel (Q) is made to ride loose upon a short fixed spindle, which is equidistant from the shafts M and N, to either of which it can be made to transfer any motion which it receives by simply slipping a pinion over the end of the one which is to be driven by it. In the diagram, the pinion is supposed to be represented by the dotted circle round the end of the screwed shaft M, so that the result of communicating motion to the wheel Q would be to move the tool horizontally. And the manner in which the movement of the horns H H′ effects this is sufficiently obvious. The spindle which carries the spur-wheel Q also has upon it a bell-crank lever, to one arm of which a pawl is attached. When this pawl is turned over, so that it rests upon the teeth of Q on one side of the arm or on the other, whatever rocking motion the lever receives serves to give an intermittent revolution in a corresponding direction to the spur-wheel Q. And this rocking motion is derived from the horns through a connecting-rod attached to the vertical rod K, at the foot of which is a second cranked lever. This lever—as well as the former one—has one of its arms slotted; by which means the

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amount of motion received, in the first place by the rod K, and secondly by the wheel Q, can be readily and accurately adjusted.

Having now a tolerably clear insight into the arrangement of the various parts in such a Planing Machine as is represented in Fig. 226, the reader who has the opportunity of examining for himself others of different construction will probably be easily able to understand their mode of action. But for his further assistance, and also for the information of those who have not that advantage, we will here briefly notice one or two of the more important of the other mechanical expedients which are to be met with in tools of this kind.

One of these—which, although the particular machine given in the foregoing engraving is not provided with it, may be found in those of larger size by the same makers—is the *Stepped Rack.* In appearance, it exactly resembles an ordinary rack cut in the direction of its length into two or more equal parts, the teeth of each part being set out of line with each other—as shown in the annexed cut (Fig. 230)—to the extent of one-half their pitch if the rack be divided into two parts—to one-third if into three, and so on. The pinion is, of course, made in a similar manner—the effect of the arrangement being to cause the teeth to work together with all the smoothness which would be obtained by pitching them two or three times as finely, without sacrificing the strength due to the coarser pitch. The latter, we may mention, is frequently severely tried, on account of the great weight of the table and the work carried by it in some of the larger planing machines.

FIG. 230. Stepped Rack.

But a rack is not the only method employed for converting the circular motion delivered to a machine of this kind into the intermittent one required for its table. An endless chain driven by rag-wheels has been used for the purpose,

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but has long been abandoned; and in one pattern of machine the same end is gained—in what is considered to be a superior manner—by placing a powerful horizontal screw within the bed, the direction of its revolution being reversed at proper intervals for giving any desired length of traverse. The arrangement of the reversing gear will be evident from Fig. 231, in which, as in that already shown in Fig. 227, the

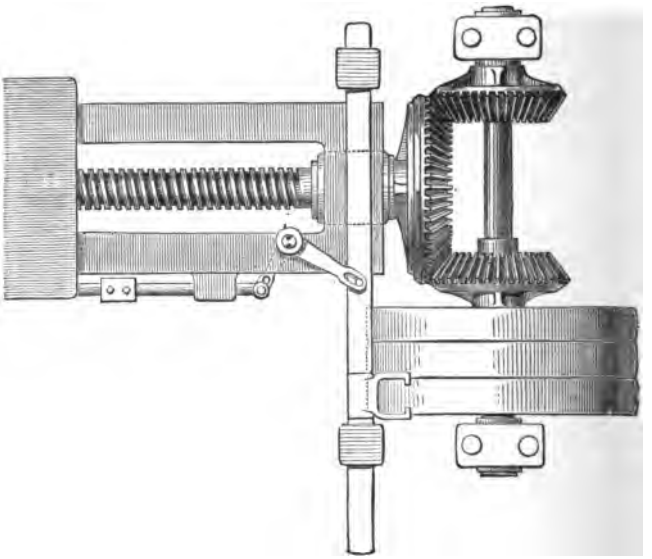

FIG. 231.—Whitworth's Reversing Gear.

motion of the table is either backwards or forwards, according as one or other of the outside ones of a set of three pulleys is driven by the strap—that in the centre being, as before, an idle pulley. The screw passes through a nut attached to the under side of the table, and has upon its extremity a bevil-wheel of sufficient size to reduce the speed of the pulleys to that required for driving the screw. Upon

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the opposite sides of this wheel two bevilled pinions gear into it, one of which is connected with one, and the other with the other of the two outside pulleys, by casting one pulley with its pinion upon a short hollow spindle, and passing through it the shaft to which the other pinion and pulley are keyed ;—their arrangement being in this respect precisely similar to that of the pinions and the pulleys marked A and B in Fig. 227. But it is evident that although, by merely shifting the strap, the screw can then be driven alternately backwards and forwards, its speed is the same in either case, so that as much time is occupied in the return as in the forward movement. This Sir Joseph Whitworth has turned to account by the simple method of reversing the tool at the end of each stroke, thereby enabling it to cut during the whole time that the table is in motion without regard to the direction in which it is going.

But whilst we are on the subject of driving and reversing the tables of planing machines, we should mention Mr. Shanks's modification of the above gearing, which, by the addition of only one bevil-wheel, provides this arrangement with a quick return motion. The additional wheel, which is of small diameter, is fixed within and concentric with the circumference of the larger wheel which appears at the end of the screw in the preceding illustration. With this the bevilled pinion which is in connection with the reversing pulley is made to gear instead of with the large wheel, into the opposite side of which the other pinion, which runs the table forwards, gears as before. The difference between the diameters of the inner and the outer wheel carried by the screw then determines the variation in the speed of the return and the forward stroke, no alteration in the size of the pinion being necessary.

A few words will suffice to explain the general principle of the *Revolving Tool-Holder* (Fig. 232), which was invented, as above stated, for the purpose of enabling the tool to cut during the return as well as during the forward stroke.

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The front of the holder carries a vertical cylinder. At the lower end of this is a recess, in which the tool is placed, and in which it can be so adjusted that the centre of its cutting edge is exactly in a line with the axis. Round the axis the cylinder is driven through exactly half a revolution every time the table changes its direction, special arrangements being provided for giving the desired feed on each of these occasions, and not at the end of the return stroke only, as in the machine described above. This mechanism, although it appears sufficiently simple when seen in operation, would appropriate far too much of our space if we were to attempt to explain it here in detail. The semi-revolution of the cylinder, which, with the earlier machines of this kind, was obtained from the alternate rise and fall of a stud working in a spiral groove cut upon the cylindrical surface, is now generally produced in preference by a gut band stretched over two vertical pulleys upon opposite sides of the machine, which in its passage from one to the other takes a couple of turns round the top of the cylinder of either one or both the tool-holders upon the cross-slide. But although this may be simple, in point of appearance it is hardly satisfactory for a highly finished machine-tool, in which conspicuous cords and bands always seem rather out of place. Owing to the prominent position of the cylinder, and the alacrity with which it whisks round, a 'patent revolving tool-holder' is better known among workmen as a 'Jack-in-the-box,' or 'Jim Crow.'

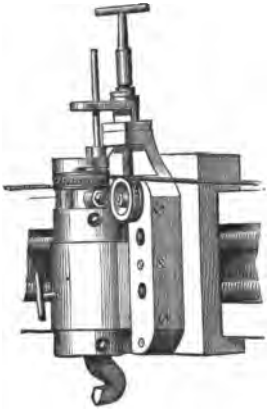

FIG. 232.—Revolving Tool-Holder.

A planing machine of either of the above kinds is not unfrequently provided with a detached tool-holder in addition

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to the one or two upon its cross-slide. This, when required, can be fixed to either of the side standards of the machine; vertical and other portions of a piece of work which it would otherwise be difficult to plane, being readily accessible to a *side-tool* supported in this manner. The feed of a side-tool is generally given by hand, but in some instances this also is made self-acting by the introduction of an additional vertical screw, so arranged as to be capable of imparting to it a sliding motion upon the standard.

In other cases, again, the side-tool is carried by an entirely independent standard, which is only connected with the body of the machine by transverse girders placed beneath the bed, the overhanging portions of which carry a side table upon which this separate standard is temporarily bolted. With this somewhat makeshift contrivance it becomes possible to operate upon the sides or edges of articles of which the size is too great for the machine to admit them in the ordinary way; the clear space between the side standards being under other circumstances the limiting dimension as to width, and the distance between the tool and the table, when the cross-slide is fully raised, determining the height which can be admitted.

A far better way of extending these limits appears to be a reversal of the present system—setting the tool in motion, together with the comparatively light mechanism required for its attachment and feed, and thus saving a large proportion of the power now uselessly expended in driving the table. For in planing small pieces of work, this mass, which is often very considerable, by requiring to be set in motion and again brought to rest at every stroke of the machine, consumes an altogether disproportionate amount of power; whilst in the case of large articles, which are frequently only too ponderous in themselves, it tends still further to overtax the powers of the machine.

Occasionally this reversal is practised in a makeshift kind of way with planing machines of the ordinary construc-

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tion. An 'angle chuck' of large size is affixed to the table in the manner in which articles to be planed are in general secured—namely, by passing bolts into the T-grooves with which its surface is provided—and to the vertical portion of this a horizontal slide carrying a tool-holder is attached. The work is laid alongside the bed of the machine, and is there kept stationary; the width capable of being thus treated by the tool depending upon the distance to which the horizontal slide can be made to overhang the bed. This overhanging position of the tool, however, necessarily tends to cause the table to leave the grooves, and so to produce unsteadiness of cut.

The dimensions which chiefly limit the applicability of an ordinary planing machine are the width between the standards and the height to which the cross-slide can be raised. The length of the bed and the extent of its traverse (or, in other words, the greatest length of cut which can be taken) should also be noted in stating the particulars of a planing machine; though the former of these does not determine the length of the work which can be treated on it in the same rigid manner that the width and height are limited. But in general the length of the bed itself considerably exceeds the other limiting dimensions—a machine capable of admitting articles 10 feet high or 10 feet wide having a bed about 36 feet long, upon which a cut of 27 feet can be taken. The largest planing machine in Sir Joseph Whitworth's workshops is capable of taking a single cut 40 feet in length from any article not exceeding 12 feet by 12 feet. The bed of this machine is 50 feet long—its grooves being probably the longest true surfaces which have ever been made. By the side of such a tool, that represented in the engraving, Fig. 226, would of course appear diminutive, but it is for that reason the better adapted for being brought within the very narrow compass of our page. The following are the particulars of it:—Length of bed, 14 feet; greatest length of cut, 8 feet;

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greatest admissible height, 3 feet; greatest admissible width, 3 feet.

For the purpose of admitting work of greater proportionate width, *Duplex Planing Machines* have been devised —two beds being fixed together side by side, each of which has an independent table. These can either be coupled together, so as to form a large single table, or they can be used separately, just as if they belonged to independent

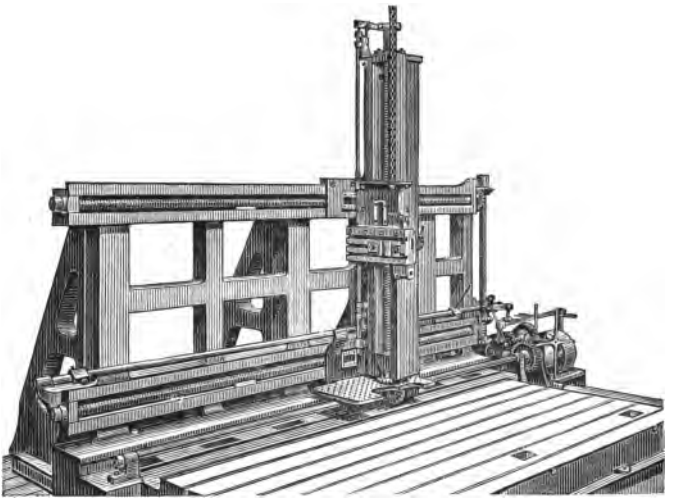

FIG. 233.—Vertical and Horizontal Planing Machine.

machines. These tools are sometimes provided with self-acting oiling apparatus, sufficient lubrication of the grooves on which the table slides being very important. In spite of the oil, however, the 'scored' state of the grooves in almost every large planing machine testifies to the great amount of friction which still exists between the sliding surfaces—although this might, in our opinion, be much reduced by the employment of some less fluid lubricant. But to this subject we shall have to revert in a future chapter. At the

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end of the bed in Fig. 226 a cistern may be observed, in which the oil is caught as it gets worked out of the grooves by the movement of the table, and from which it can be drawn off from time to time.

The difficulties attending the treatment of articles of great size or weight in planing machines with the ordinary moving tables, for the most part disappear when the construction shown in Fig. 233 is adopted. In this, which for distinction is called a *Vertical and Horizontal Planing Machine*, the work is kept stationary, so that the usual traversing table is entirely dispensed with, and is replaced by a simple fixed base-plate. The moving parts having thus the comparatively light duty of giving motion to the tool (or tools), there results a great reduction in their weight, with a proportionate saving in the power expended in driving the machine, notwithstanding its capacity for operating upon large or heavy articles being so much increased. And at the same time the space occupied by a planing machine of any stated capacity is largely reduced, which in itself is often a high recommendation. In the machine represented in the engraving, a horizontal cut of any length up to 16 feet, or a vertical cut of any height up to 9 feet, can be taken, but larger sizes are used, in which either or both of these dimensions can be considerably exceeded. The feed and the traverse may be in either direction, and they are self-acting, and the vertical slide is provided with a quick return motion.

In one variety of planing machine—the *Edge Planing Machine*—which is intended only for operating upon the edges of wrought-iron and other plates, a similar system has been in use for a considerable time. Its principle consists in providing a fixed table of sufficient length to admit of the longest plate which has to be treated being held down upon it. This can be done—even though there may be no available holes in the plate itself—by fixing standards at the two ends of the table, and placing a girder between them con-

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taining a series of long screws, between the ends of which and the supporting surface the plate can be clipped. Parallel to the table, and running along its whole length, is a slide-face, upon which a long screw drives a carriage bearing a tool-holder, the motion of which can be reversed by a simple arrangement, at any required points. If the tool-holder be of the ordinary construction, increased speed is of course desirable during the backward journey, and, by running a crossed strap upon a pulley of smaller size than that by which the screw is driven, this is easily obtained, as pointed

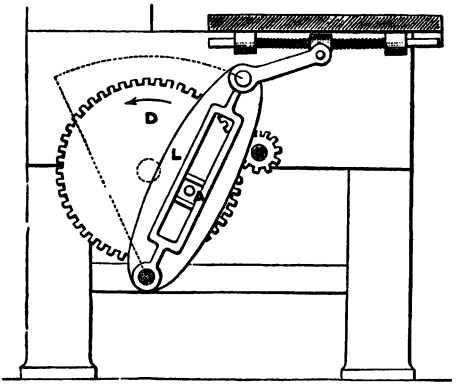

FIG. 234.—Link Planing Machine.

out in another chapter (Chapter X.); but with the revolving tool-holder, which has been applied to these machines, and for which they seem to be very well adapted, no need for a quick return exists. In this way it is easy to see that a machine could be made capable of planing any length of edge which is likely to be required.

Passing now from large planing machines to small ones, we find other methods available for producing the motion of the table, which could not be applied when any considerable length of traverse is required. For this purpose —that is to say, for converting the rotary into rectilinear

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motion—some form of crank will no doubt suggest itself to the student of mechanics; and small planing machines have been made on this principle, the table being driven by means of a connecting-rod, from a pin in the face of a horizontal disc placed beneath it. By altering the distance between this pin and the centre of the disc, the throw of the table could be adjusted. But to this arrangement there are two serious objections; in the first place, it causes one-half of the time to be wasted, through the return stroke being neither accelerated nor made use of, and, secondly, there is a great variation of speed during each cut. As a remedy for these evils the following method has been employed :—A vertical disc (D, Fig. 234), having upon its face an adjustable pin (A), is so supported below the table as to form an overhanging crank. The circumference of the disc is toothed to enable it to be driven by a pinion, and in close proximity to its face is a slotted link (L), pivoted to the framing at its lower, and attached to the table by a short connecting-rod at its upper, end. The effect of causing the disc to revolve in the direction indicated by the arrow is thus to drive the table forwards powerfully, and at a slow speed, these conditions being reversed during its return.

But for small work it appears to have been generally conceded for some time past that there is an advantage in giving the motion to the tool, rather than to the article to be treated by it. It is entirely on this principle that the work is performed by the instruments which we have next to consider — namely, *Shaping Machines.* These are now amongst the most useful of engineers' tools, performing, as they do, an immense variety of minor operations, which were formerly effected by hand-chipping and filing in a much less rapid and less satisfactory manner. Fig. 235 shows a *Bench Shaping Machine*, which may be taken as a good representative of a class, amongst the

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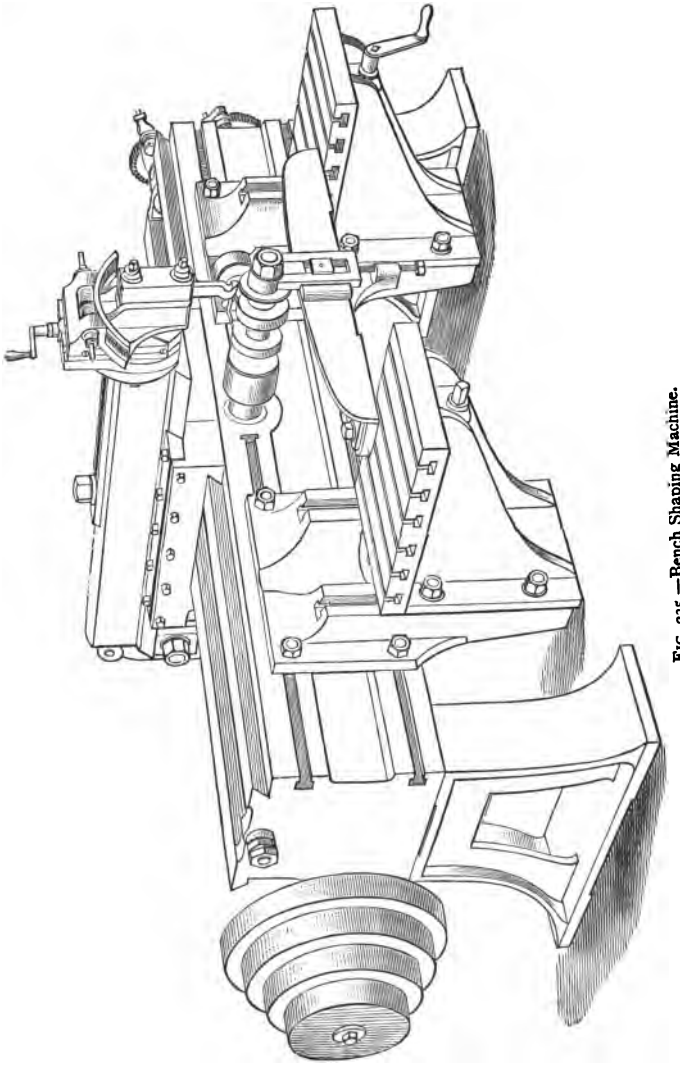

FIG. 235.—Bench Shaping Machine.

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individual members of which even more than the usual amount of variation may be found.

The duties of these machines are twofold; one of them being to render flat such surfaces of moderate size as from their position, or from other causes, could not be conveniently treated in a planing machine; the other, to work up any curved faces of which the radius (for the line of curvature must form part of the circumference of a circle) does not exceed a certain fixed limit.

And in connection with the first of these we may mention—and it should perhaps have been pointed out before—that with planing machines in which the motion of the table is reversed by shifting the strap, the reversal does not take place with the exactness which is in some cases desirable, as, for instance, in planing surfaces of which the ends are in close proximity to raised portions of the work—although there is always a balance-weight, so arranged as to prevent the strap from resting upon the idle pulley, and this tends to hasten the operation. This circumstance alone frequently gives the advantage to a shaping machine, in which the length of stroke allowed to the tool can be adjusted with the greatest nicety.

In the machine shown in the engraving, the bed bears upon its upper surface a sliding head, capable of traversing its entire length. Upon the front of it—in addition to an arbor at the centre, with which we will not for the moment concern ourselves—there are two adjustable tables, for supporting the work, and for bringing it within range of the tool. The tool-holder in which this is fixed is carried by the head at the forward end of its large and powerful cross-slide, and to the sliding portion a reciprocating motion can be given by means of the link arrangement above described (Fig. 234). In this case, however, the disc is attached to the head, and the pinion is free to travel with it to any part of a horizontal back-shaft, upon the extremity of which is the conical driving-pulley. By altering the distance

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between the pin (A, Fig. 234) and the centre of the disc, different lengths of throw can be given, and by means of the large hexagon nut which appears at the top of the slide—which forms the point of attachment of the connecting-rod belonging to the link—the position of the tool with respect to the front of the bed can be adjusted. With these arrangements, then, it is possible to plane up any flat surface which can be brought within reach of the tool, provided only that its width and its length do not exceed the maximum stroke of the cross-slide and the extreme traverse of the head respectively. And for this work the machine is made self-acting by merely giving an intermittent feed—derived from the back-shaft at the further end of the bed—to the screw by which motion is given to the head.

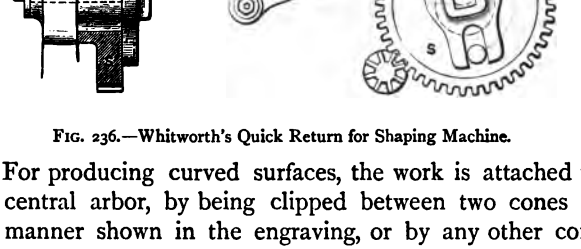

FIG. 236.—Whitworth's Quick Return for Shaping Machine.

For producing curved surfaces, the work is attached to the central arbor, by being clipped between two cones in the manner shown in the engraving, or by any other convenient means. The cap of a piston-rod is there represented in position for having the curved portions of the eye planed up concentrically with the hole which runs through it; these—since they do not form a complete circle—being incapable of being turned in the lathe. Resting upon both the tables is a short girder, with an adjustment at its centre for supporting the extremity of the arbor—this, as well as the arbor itself, being easily removable when required. The curvature is produced by giving the feed-motion to the

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arbor instead of to the head, the radius of the curve being ruled by the distance from its centre at which the tool is set in the first instance. The greatest diameter of work which can be thus operated upon by this machine is 12 inches, the maximum length of stroke—which equally regulates the width of surface which can be planed, whether it be flat or curved—being 13 inches. The greatest length of flat surface which it can treat is 4 feet 1 inch.

The construction of the tool-box upon the cross-slide will be obvious to the reader who has followed the description of that shown in Fig. 228, the chief point of difference between them being that in this case a tangent screw taking into the segment of a worm-wheel is substituted for the slotted hole and bolt by which inclination can be given to the tool in an ordinary planing machine. The object of these is to enable concave surfaces also to be planed, the work being kept at rest, and the feed given to the tool by means of a handle placed upon either end of the tangent screw.

The stroke of the tool is not, however, by any means always produced in the manner mentioned above. In the case of small machines with a maximum stroke of not more than six inches, the additional complexity of the gearing required for giving increased speed during the return more than outweighs its advantages; but, with the exception of these, the generality of them will be found to be worked by the following ingenious arrangement. Upon a convenient part of the head is placed a spur-wheel (S, Fig. 236) capable of revolving freely upon a fixed overhanging shaft of large diameter. Through this shaft—but not concentric with it—runs a spindle, having upon its extremity a slotted arm (P), which it keeps in contact with the face of the wheel. Thus supported, each would be able to revolve independently of the other—the wheel upon its fixed shaft, and the arm round the axis of its spindle—but their revolutions would be eccentric to one another. But by forking the end of the arm and fixing a pin in the face of the wheel, they

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are compelled to revolve together; the velocity of the arm—if that of the wheel be uniform—varying constantly, as the pin which drives it, and the spindle which carries it, approach and recede from each other. A dovetailed groove at the opposite end of the arm, at any part of which the pin of the connecting rod (R) can be set, provides the requisite adjustment for the length of the stroke.

Shaping machines are not unfrequently furnished with two heads as well as two tables, or an arbor and one table. Each part can then be used separately, and becomes to all intents and purposes a distinct tool, the bed alone being common to the two. A vertical face with T-grooves in it is sometimes a useful addition to the table.

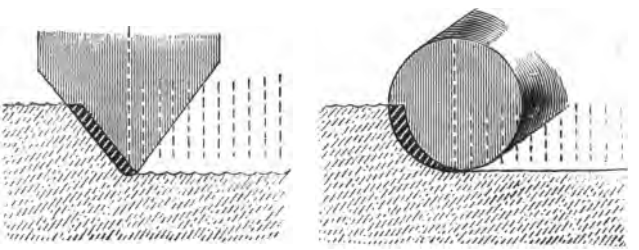

FIG. 237.—Diagram of Sections of Planed Surfaces.

The tools used in planing and in shaping machines resemble one another so closely that we have purposely deferred the few lines we have to devote to the former till the latter could also be included. In planing metal, as already mentioned, the general truth of the surface produced depends upon the accurate guidance of the work and of the tool, and not upon the form of the edge by which the individual cuts are made. This being so, a pointed or but slightly rounded tool is generally employed, the preference being given to these—as in metal turning—on account of their combining great strength of form with facility in cutting. A series of grooves is the result, of

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which the curvature of the extremity of the tool and the amount of feed determine the depth and the distance apart, the slight ridges between them being immaterial for many purposes. But when general flatness has been obtained in this manner, greater smoothness can be easily given to a surface, when required, by going over it a second time with a broad-edged tool which removes the ridges. Mr. W. F. Smith, of Manchester, has shown that greatly increased smoothness may be obtained in the first instance by using a tool with a loose cutter of circular section instead of the ordinary pointed tool. The diagram (Fig. 237) shows the effect of each, the vertical dotted lines indicating the amount of feed—nine cuts to the inch in each case. A drawing of one of these cutters with its holder has been given in Fig. 199 amongst the tools for turning metal, and what is there said about it applies equally whether it is used in the lathe or in the planing machine.

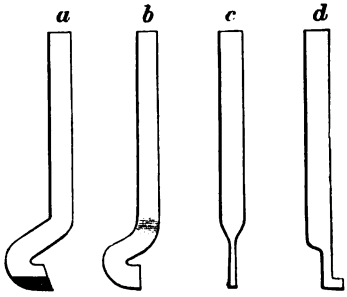

FIG. 238.—Planing and Shaping Tools.

Much resemblance may also be noticed between the turning-tools in Fig. 192, and those ordinarily used for planing and shaping which are given in Fig. 238. Of these the first, marked *a*, is the usual tool for roughing, its point being slightly rounded off, as appears in the preceding diagram. For smoothing, a tool resembling this, but having a broad straight edge instead of a point, is employed. Of the others, *d* is for under-cutting, and *b* and *c* are two kinds of parting tool which are used for making through cuts of as small width as possible, so that their edges are kept as narrow as is consistent with their own safety. In shaping

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machines, right and left side-tools, similar to the turning-tools of the same name, are also sometimes employed. The cutting edge should be made in a line with the back of the

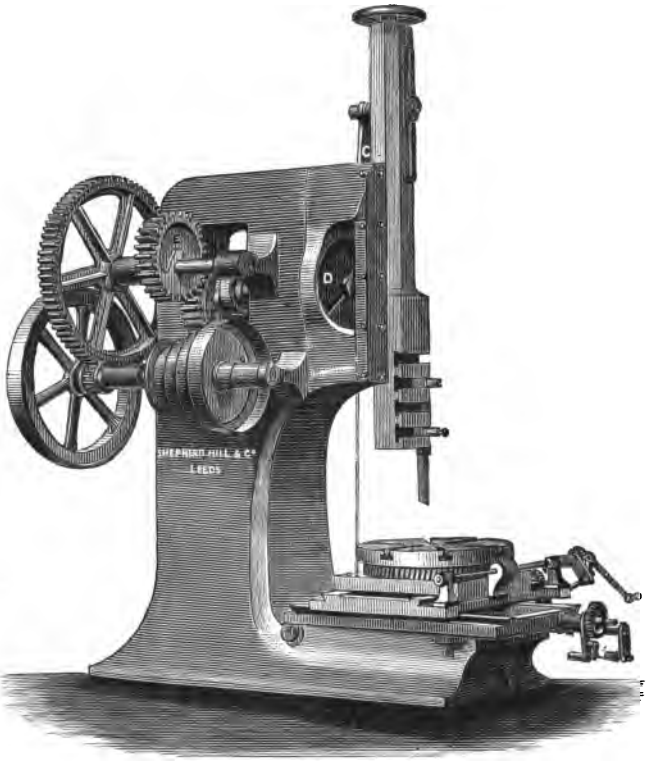

FIG. 239.—Vertical Shaping or Slotting Machine.

shank, as in *a* and *b*, Fig. 238, so that the tool may spring over the work rather than dig into it.

For many purposes Vertical Shaping Machines, or *Slotting Machines* as they are generally called, possess advantages over those just noticed, in which the travel of the tool

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is horizontal. In principle these two classes of tools differ but little, each cut in either case being a copy of the straight sliding bed ; but in practice there are great differences between them, shaping machines being for the most part some of the lightest and most delicate, whereas slotting machines are amongst the heaviest of ordinary workshop cutting-tools. To the much more arduous nature of their duties this fact bears testimony—that their driving apparatus is almost invariably either double- or treble-geared, the latter being by no means uncommon.

The slotting or vertical shaping machine represented in Fig. 239 has gearing of the former kind, its framing and the table below its slide for the support of the work having much resemblance to those of a drilling machine. Its capabilities are therefore estimated in a very similar manner, the maximum stroke of the slide, and the space between the point of the tool and the nearest vertical portion of the framing, ruling respectively the length of cut, and the distance from the edge of the work at which it can be made. In the present instance, the greatest possible length of stroke is 13 inches, and the largest diameter of work in any part of which a cut can be given, is 4 feet 6 inches—half of this (2 feet 3 inches) being therefore the distance between the tool and the framing.

But a slotting machine must be able to accommodate itself to the performance of duties of a very varying character, for besides the 'slotting' (or perhaps more properly the slitting) of circular holes so as to give them the elongated section from which these tools have obtained their name—which section, as we have seen, can now be produced by other means—they are employed for almost all the paring and shaping which is required in the treatment of work of a heavy description. Ready adjustability of the height of the sliding-bar and of the length of its stroke is therefore essential, whilst a quick return is as desirable in this as in the other cases of single-acting tools which we have been

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examining. In the present example the following provision is made to supply these several wants, and also to impart to the table the requisite feed-motion, for it is evident that the construction does not admit of this being given to the tool.

At the back of the vertical slide is a disc (D), having in its face a radial groove, in any part of which, by means of an adjusting-screw, a projecting stud can be set. Upon the amount of the eccentricity of this stud the length of the stroke of the machine depends, its motion being transmitted by a connecting-rod (C). This, however, is not attached to any fixed portion of the sliding-bar, but to a pin which can

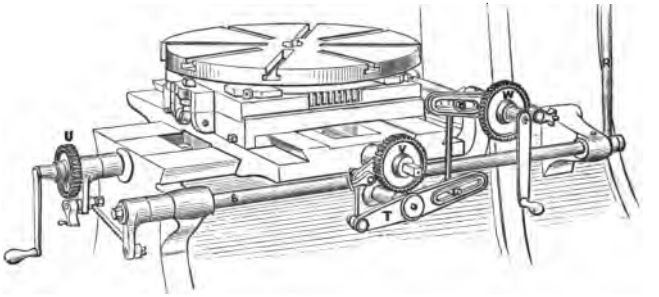

FIG. 240.—Self-acting Gearing for Slotting Machine.

be moved upwards or downwards—also by means of an adjusting-screw—in a long slotted hole in the upper part of it. The hand-wheel at the end of this adjusting-screw appears in the engraving at the upper extremity of the sliding-bar, which can thus be readily raised or lowered.

In order to render the speed faster in the upward than in the downward stroke the disc is not driven at a uniform speed. It receives its motion through the wheels marked E E′, and these being elliptical instead of circular, so vary its velocity that the speed which it imparts to the sliding-bar is slow and comparatively uniform whilst the tool is cutting, and of greatly increased rapidity during the return stroke.

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We have now only to examine the construction of the table and the arrangements by which its movements are made self-acting. These are clearly shown in Fig. 240 which represents in outline the self-acting table of a slotting machine of somewhat larger size than that in the general view (Fig. 239), seen from the opposite side.

The table is capable of receiving three separate horizontal movements; a slide being so arranged that it can approach or recede from the standard, a cross-slide providing for its travelling in a direction at right angles to this, and a pivot at its centre enabling it to revolve about its axis. The two slides—which together form what is termed a 'compound slide'—are worked by screws in the ordinary way, and the table is turned by a worm taking into a worm-wheel immediately below it. Ratchet wheels with double pawls are placed upon the ends of the two screws, and upon the shaft which carries the worm, so that any one of these can be made to receive an intermittent feed-motion in either direction by giving a reciprocating movement to the arms to which the pawls are attached. This movement they constantly receive from the shaft S, which is driven backwards and forwards through a portion of a revolution by the vertical rod R whenever the machine is in motion. R, in turn, derives its motion from a cam-groove on some convenient part of the driving-shaft of the tool-slide, its upper end being attached to a slotted link, by which the amount of its rise and fall—and consequently of the feed of the table—can be regulated. In Fig. 239 a portion of the cam-groove can be seen on the face of the wheel E'. The manner in which the motion is imparted by the shaft S to the ratchet wheel U is sufficiently evident, and the expedient by which one of a pair of bevil-wheels can be made to slide to any part of its shaft whilst still sharing its rotation—which is here employed for giving a rocking motion to the lever T from the shaft S—must now be too familiar to the reader to need further description. In addition to these motions the

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tables of slotting machines are occasionally provided with apparatus for enabling other curves to be cut. Provision is also sometimes made for tilting the table instead of having its surface always horizontal.

With respect to the tools for these machines, it is evident that some modification of the forms employed for planing and shaping is required to meet the altered conditions under which they are used; one main point of difference being in the direction of the thrust upon them. Frequently it is necessary for a slotting tool to be able to work in a very limited space; for instance, in cutting a key-bed in the boss of a wheel or in commencing a cut from any drilled hole. For such purposes a *Parting-tool* resembling that shown on the left-hand side in Fig. 241 must be employed, but in most other cases the form of tool on the right is more convenient. This is called a *Round-edge*, a *Diamond-point*, or a *Keyway-tool* according to the shape of its cutting edge, the edge of the parting-tool being also rounded when occasion requires it. Where, however, there is sufficient room the position of the tool is often reversed, the shank

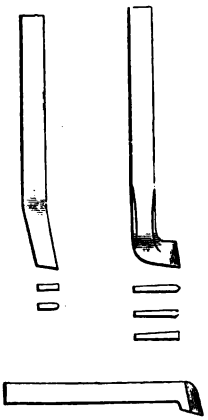

FIG. 241.
Tools for Slotting Machine.

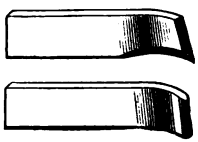

FIG. 242.—Roughing and Finishing Tools for large Slotting Machine.

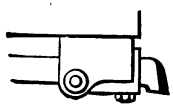

FIG. 243.—Swivelling Tool-Holder for Slotting.

being fixed below the bottom of the tool-slide instead of on the face of it. The *Hook-tool* shown below the other two in

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Fig. 241, is intended to be used in this manner, and so also are the powerful *Roughing* and *Finishing-tools* represented in Fig. 242.

This position of the tool admits of the introduction of the simple arrangement shown in Fig. 243, for preventing the possibility of the cutting edge being injured by coming

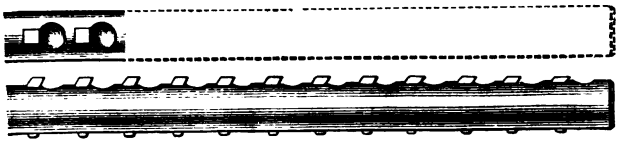

FIG. 244.—Stepped Keyway Cutter-Bar.

into contact with the work during the upward stroke, during which, if the tool encounters any resistance, the *Swivelling Tool-Holder* yields by turning on its pivots. During the downward cut, on the other hand, the tool is as unyielding as if attached directly to the slide.

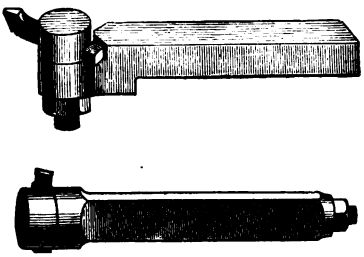

FIG. 245.—Timms' Tool-Holders for Planing, Slotting, &c.

The larger sizes of the Vertical and Horizontal Planing Machine already noticed (Fig. 233) are provided with two such tool-holders placed side by side, so that two tools can be used at once. Important economy may sometimes result either from thus taking a rough and a finishing cut at one operation, or by 'stepping' two roughing-tools, so that one shall follow the other.

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An example of a tool in which the 'stepping' system is carried much further is the *Stepped Key-way Cutter Bar* (Fig. 244), by which a finished groove is cut in the boss of a cast-iron wheel by once passing the tool through it. In this each cutter is formed from a separately adjustable piece of steel. Tools with loose cutters have also been applied to ordinary planing, shaping, and slotting. Two forms of recent introduction are shown in Fig. 245.

In the foregoing Planing, Shaping, and Slotting Machines, straight cuts only can be taken, the traverse of the tool being in every instance controlled by the straight slide to which it is attached. Some of these, as we have seen, can be so arranged that the self-acting feed-motion shall place successive cuts in a circular path, instead of in a straight one, so that within certain limits they can be used for surfaces curved in one direction, and to a uniform radius; but working to irregular curves can in general only be accomplished with them by very careful hand-feeding. And for surfaces curved in more than one direction these machines cannot be used without the addition of special apparatus.

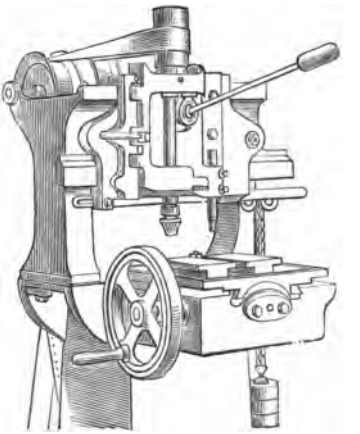

FIG. 246.—Edge-Milling Machine.

But the inventive powers of the designers of machine-tools have proved quite equal to fulfilling these requirements by other means. Copying machines, many varieties of which are now made, enable articles to be shaped—either automatically, or with but very slight alteration on the part of the workman—even though they may possess considerable

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irregularity of outline. This is effected by transferring the desired curve from a previously prepared template.

The *Edge-Milling* or *Contouring Machine* (Fig. 246) is a good example of this class of tool. It will be seen to consist mainly of a compound slide arranged vertically over a small table, to which a slow traversing motion can be given. The vertical portion of the slide carries on the left-hand side a revolving spindle, the lower end of which receives the tool, and on the right a fixed tracer. The piece of work to be operated upon and the template to serve as a pattern for it being secured side by side on the face of the table, a slow traverse is given to them by means of the hand-wheel on

FIG. 247.
Edge Milling Tool.

FIG. 248.
Moulded Milling Tool.

FIG. 249.
Flat Milling Tool.

the left of the table. Meanwhile the tracer is kept in contact with the template by a weight acting upon the horizontal slide, and the slide, tracer, and tool being thus compelled to follow the outline of the template, this outline is reproduced upon the work in hand. In a similar manner vertical contours can be copied by the vertical slide, or in some cases the two can be made to act simultaneously.

By securing similarity (and therefore interchangeability) in a series of copies made in this manner from any cam or other difficult portion of machinery, these machines prove their utility in perhaps the most legitimate way ; but they can often be advantageously used also without templates, for facing small flat surfaces, &c. Revolving or Milling-tools seem, indeed, to be yearly coming more into favour, and in very many instances 'Milling Machines' now

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render unnecessary the use of hand-files in the operations of 'fitting' or 'finishing.'

The cutting portion of a plain *Edge Milling Tool* adapted for use with the Contouring Machine, Fig. 246, is shown in Fig. 247, and in Fig. 248 is a moulded cutter of a similar kind. But the tools are varied considerably both as to form and size, according to the requirements of each case. Sometimes flat cutters, as Fig. 249, may be substituted for circular ones, or the cutting portion may be in one piece with the shank. Others, again, are made from discs of steel brought to a suitable outline at the edge, after the manner of the cutter for finishing wheel teeth, Fig. 250.

Sharpening tools of this class is a work of some difficulty, the necessity for keeping the entire series of cutting-edges similar in form and equally distant from the centre, rendering it especially so in the case of such tools as Fig. 250, in which the curved outer faces must be ground. When the grinding can be confined to the radial faces—as in Fig. 248—the operation is less difficult.

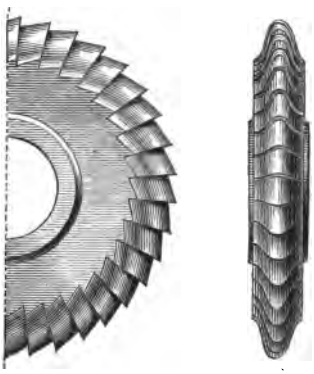

FIG. 250.—Milling Tool for shaping Teeth of Wheels.

The requisite uniformity however—secured in the first instance by forming the teeth of such cutters in milling machines specially arranged for the purpose—can in either case be maintained by the employment of *Cutter Sharpening Machines.* In these the grinding is done by means of small emery wheels, of the use of which in treating hardened steel some examples will be found in a subsequent chapter.

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CHAPTER IX.

ON PUNCHING AND SHEARING MACHINERY.

THE peculiar action of hand punching and shearing tools has already been pointed out. Machine tools acting in a similar manner are largely used for operating upon metal plates and bars of greater substance. Hand shears, for instance, can with difficulty cut through an iron plate $\frac{1}{8}$th of an inch thick, whereas the blades of a shearing machine

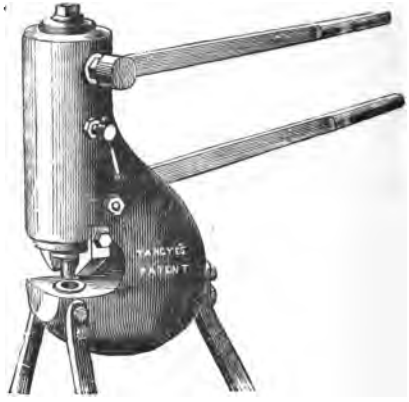

FIG. 251.- Hydraulic Bear.

will pass through one as much as an inch and a half in thickness, and will do so with a rapidity and an appearance of ease which give but little idea of the power actually expended.

Before noticing the stationary tools in which heavy work of this kind is chiefly done, and in which punches and shears are frequently associated together in the same machine, we should mention some portable forms which, like the punch-

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ing bear (Fig. 94), occupy a sort of debateable ground between hand tools and the present class. These are generally arranged either for punching only, or for shearing only, and as they depend upon the continued application of the small force obtainable from the human arm, their operations are necessarily slow. The principle of the hydraulic press has been very successfully applied to these portable punches and shears.

Fig. 251 represents a *Hydraulic Bear*, with which holes of as much as 1¼ inch in diameter can be punched in wrought iron 1 inch in thickness, by the power of only one man. Its form will be seen to bear a general resemblance to that of the screw-punching bear (Fig. 94). Into the action of the hydraulic press we cannot here enter fully, but the general construction of this tool will be easily understood from Fig. 252. In this, which is a vertical section through it, A is a cistern containing a supply of water, C is the plunger of the force-pump D, and B the lever by which it is worked. E is the inlet-valve by which water enters the pump when the plunger is raised, an outlet-valve at the foot of this allowing it to pass into the cylinder F on the descent of the plunger. In the cylinder F is the ram, H, which has a cupped leather packing at its upper, and the punch at its lower end. L is a lever for raising the ram, and so withdrawing the punch from the hole which has been made by it. The student will be aware that (friction neglected) the pressure exerted by the ram exceeds that applied to the plunger inversely in the proportion which the area of the

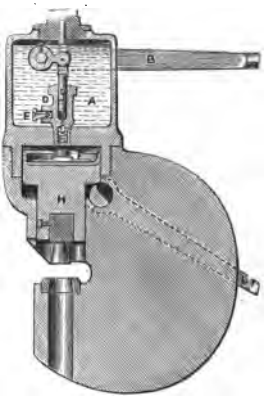

FIG. 252.—Section of Hydraulic Bear.

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latter bears to that of the former; so that if, for example, their diameters be half an inch and five inches respectively a pressure of one ton on the plunger will give 100 tons on the ram.

Besides the punching bear given in Fig. 251, other forms of hydraulic punch, both portable and stationary, are to be met with. When an 'open mouth' is unnecessary, as in punching the webs of rails, &c., a more advantageous disposition of the metal of the framing in the neighbourhood of the punch becomes possible, the vertical portion being made in two parts, and the rail or bar which is to be punched being passed between them, the arrangement being known as the 'close mouth.'

FIG. 253.—Portable Hydraulic Shears.

The *Portable Hydraulic Shears* (Fig. 253) have a close mouth; but in all other main points this tool is similar to the punching bear just described. The lever for raising the ram is omitted in the figure, its position, when in use, being on the spindle A. During this operation the screw immediately below the pump-lever is slackened, a stop-valve in connection with it then allowing the water in the cylinder to pass back into the cistern.

Hand-punching may also be performed, and in a much more rapid manner, by means of a *Fly Press*, such as Fig. 254, which, at first sight, might be thought actually to give off more power than had been applied to it—a result which every student of mechanics knows to be an absolute impossibility. One of these instruments may be occasionally seen, mounted on a 'trolley,' by the side of our lines of railway, with which two men are able to punch a hole nearly an inch in diameter through the 'web' of a rail

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perhaps three-quarters of an inch in thickness. The explanation of its action lies in its power of accumulating the force applied to it, which, although in itself it may be small, is continued for a sufficient time to produce these apparently disproportionate results. The fly—which generally consists of two heavy balls of metal at the extremities of the lever of the press—is gradually brought from a state of rest to one of rapid motion by continued effort on the part of the workmen—the maintenance of its speed being assisted by its descent, due to the revolution of the screw. But, inasmuch as it parts with the whole of its

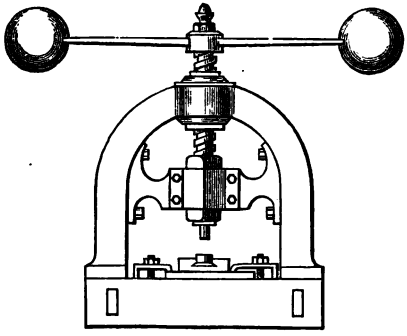

FIG. 254.—Fly Press.

momentum almost instantaneously on the punch coming into contact with the rail, the results are proportionate to the force and the length of time expended in bringing the fly to its full speed, and not to the duration of its performance.

In stamping coins, and some other processes which are rather beyond our limits, fly presses of much greater size and power are employed, the recoil—when the motion is quite suddenly arrested, as it frequently is in such cases—being sufficient to raise the screw to its original position.

Passing now to the stationary forms of punching and shearing machines, which belong more properly to our sub-

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ject, the first which claims our attention is the *Lever Punching Machine*, of which an outline diagram is given in Fig. 255. Although one of the earliest and simplest of these machines, it possesses certain advantages over the somewhat neater arrangements presently to be noticed, which have caused it to be generally preferred by boiler makers and others, to whom an efficient punching machine is an essential. Its construction will be easily understood from the engraving. The punch is attached to the lower end of a guide-bar, which is connected with the shorter arm of its

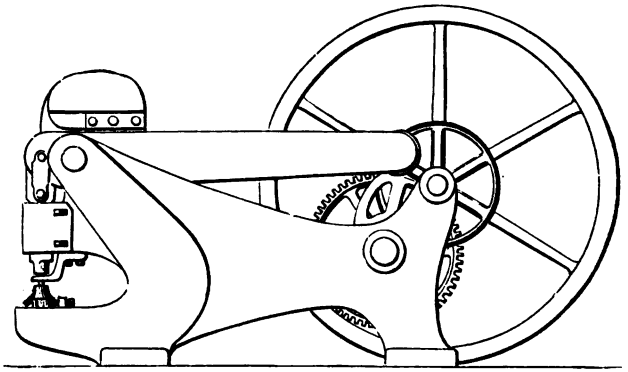

FIG. 255.—Single Lever Punching Machine.

powerful lever, so as to rise and fall with it. The longer arm of this lever—which carries a roller at its extremity—rests upon the edge of a slowly revolving cam—its motion being derived from the fly-wheel shaft by means of a spur-wheel and small pinion. It will thus be seen that the revolution of the cam, and, consequently, the motion of the lever, cannot be arrested without also bringing the fly-wheel to rest. Its momentum is therefore available for overcoming any resistance which the punch may encounter. After each descent the punch is raised by the mere weight of the

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longer arm of the lever. The following advantages accrue from regulating the motions of the punch by a cam, instead of by an eccentric, as in the machines described below. In the first place, it follows that the descent of the punch can be made perfectly uniform ; 2ndly, that its return can be accelerated to any required extent ; and, 3rdly, that by causing it to remain perfectly stationary between the end of one stroke and the commencement of the next—for which it is merely necessary for a portion of the cam to be made concentric—ample time can be given for the workman to place the plate correctly.

We have already called attention to the hollow cast-iron frames which are now generally to be met with in machine-tools. In the case of punching machines they are required to be of unusual strength to resist the severe strain due to the passage of the punch through the plate. This is secured by forming at the working end of the frame a powerful fixed jaw, to the upper part of which the lever is centred, the bolster or *die* being placed upon the lower part. The distance between the inside of this jaw and the centre of the punch is an important factor in determining the useful qualities of these machines, since it limits the distance from the edge of a plate at which any hole can be punched by them. But every increase in this distance requires that much more than an equal increment of strength be given to the jaw.

Above the lever, at a short distance from its fulcrum, a pair of knives may be observed in Fig. 255, an addition which enables this machine to be used also for shearing when required. Their position, however, is by no means a convenient one, the most advantageous height for them being that occupied in this instance by the punch and die. Some machines of this kind, indeed, are made for shearing only, in which case knives are substituted for the punch and die, the upper one being worked by the lever and cam in the manner shown in the diagram ; and it must be con-

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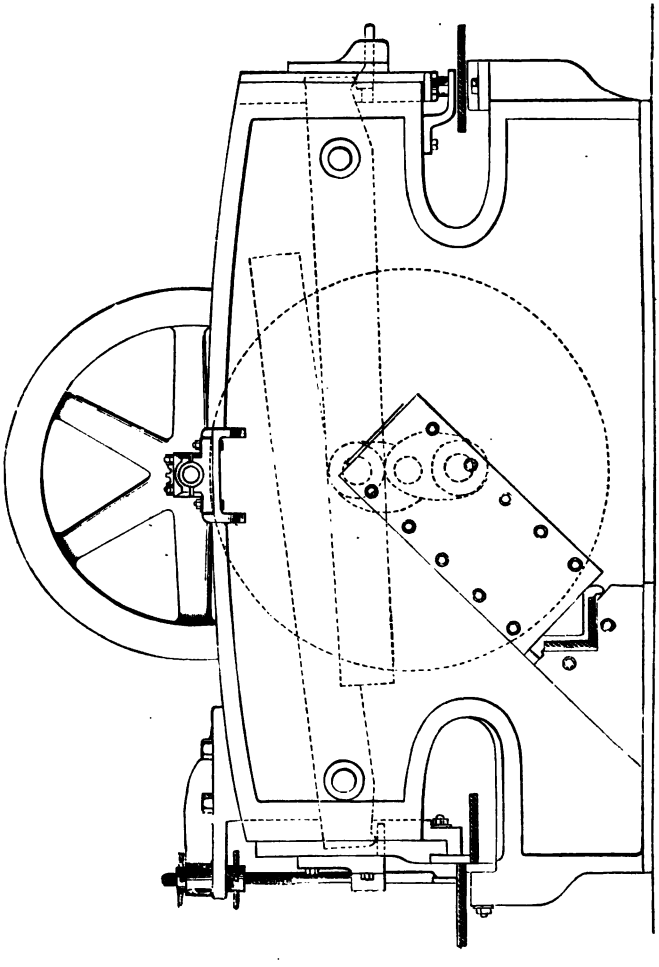

FIG. 256.—Double-Lever Punching and Shearing Machine.

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fessed that the arguments in favour of this method of driving are as forcible for shearing as for punching.

A combined punching and shearing machine is shown in Fig. 256, which, whilst it possesses much of the compactness of appearance of those on the eccentric system next to be described, retains the advantages of the cams and levers already mentioned. The shears are placed on the same level as the punch, but at the opposite extremity of the machine, so that the framing has in this case a jaw at each end, the two independent levers by which they are worked being within the hollow of the framing. The cams by which motion is given to the levers are fixed upon the spindle of a large-sized spur-wheel (shown by dotted lines in the engraving), which is driven by a small pinion on the fly-wheel shaft; and since the greatest radius of the one cam is on the same side of the shaft as the smallest radius of the other, each lever is raised alternately. By this arrangement it becomes impossible to put an undue strain upon the machine by attempting to use it for both punching and shearing at the same moment. It may be observed that there are several points of difference between the cam and lever of the single-ended machine and those of the combined machine which we are now discussing. In the present instance the cams do not act upon the extremities of the longer arms of the levers—which they could not do without considerable addition to the total length of the machine. Consequently the power obtained is proportionately reduced.

In Fig. 257, which represents a partial section of the punching end of one of these combined machines, some further points of difference may be noticed—amongst others the transference of the friction roller from the long arm of the lever E to the portion B of the cam C, at which the greatest pressure is exerted, and the insertion of the nose or short arm into a recess in the slide which carries the punch, instead of their connection being established by separate links. One great advantage of this is the facility which it

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affords for throwing the punch out of gear, in the manner explained below. To ensure the weight of the lever being competent to withdraw the punch and to raise the slide, its length is made much more than sufficient to reach the cam at the centre of the machine. One other portion of this tool demands a few words of explanation, viz. the projection which appears in Fig. 256, extending downwards from the centre at an angle of 45°. Near its lower extremity an

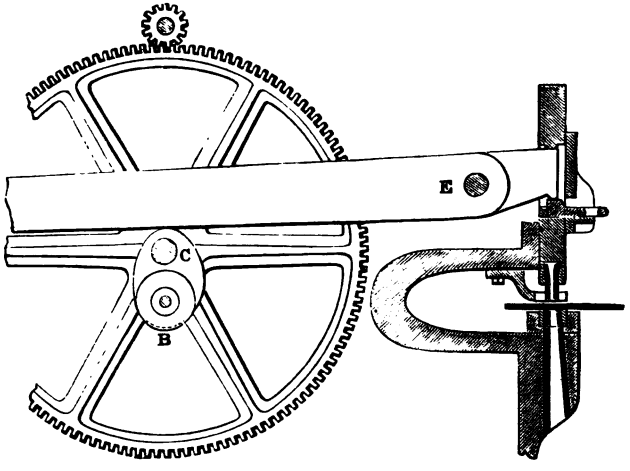

FIG. 257.—Section of Punching End of Double-Lever Machine.

L-shaped opening may be noticed. In this is a pair of shears adapted for cutting bars of angle iron, the upper knife being driven by an eccentric at the end of the shaft which carries the spur-wheel and cams. But the inferiority of this method of driving will be shown in connection with the punching and shearing machine, which we have next to describe. For cutting other sections of rolled iron various other forms of knife are employed.

Fig. 258 shows a combined *Punching and Shearing*

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Machine, in which both the shears and the punch are worked by eccentrics; the compact form which can be given to the framing of machines of this kind contrasting very favourably with those of the lever punches and shears which we have been discussing. Within the hollow framing is a strong horizontal shaft, upon which is fixed the large and powerful spur-wheel which appears in the centre of the figure. At the extremities of this shaft are eccentrics connected with the upper knife of the shears and the punch respectively, one of them always rising during the descent of the other. The manner in which the vertical movement of the slides to which the punch and the knife are attached, is obtained from these eccentrics is slightly dissimilar, owing to the difference in their respective requirements. The shear-blade is attached to the pin of the eccentric by means of a link (the upper joint of which can be seen in the engraving), so that it rises and falls at every revolution of the shaft, and can never be disconnected from it. For in the case of shears this is never required, although for a punch it is a great desideratum. A slight modification at the punching end of the machine enables the connection to be instantly broken and as quickly re-established. The link is not perforated at both ends, as before, but the lower end is made to drive the punch by simply pressing downwards upon a projecting portion at the centre of the slide, with which it only comes into contact when its lower extremity is central. A handle at the end of the machine enables the link to be turned aside so as to miss the projection during its descent, so that the punch remains at the top of its traverse—a weighted lever, working on the centre which appears in the figure above the jaw, continually retaining it in that position when it is disconnected from the link. A lever punch, however, admits of still more simple means being employed for this purpose. The opening in the slide, into which the nose of the lever is inserted, is made of sufficient length to admit not only the lever, but also a loose piece, or

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'block,' which can be slipped in below the lever through an opening in the framing. This block appears in both the outline elevation (Fig. 256) and the section (Fig. 257). On the punch in its descent coming into contact with the work,

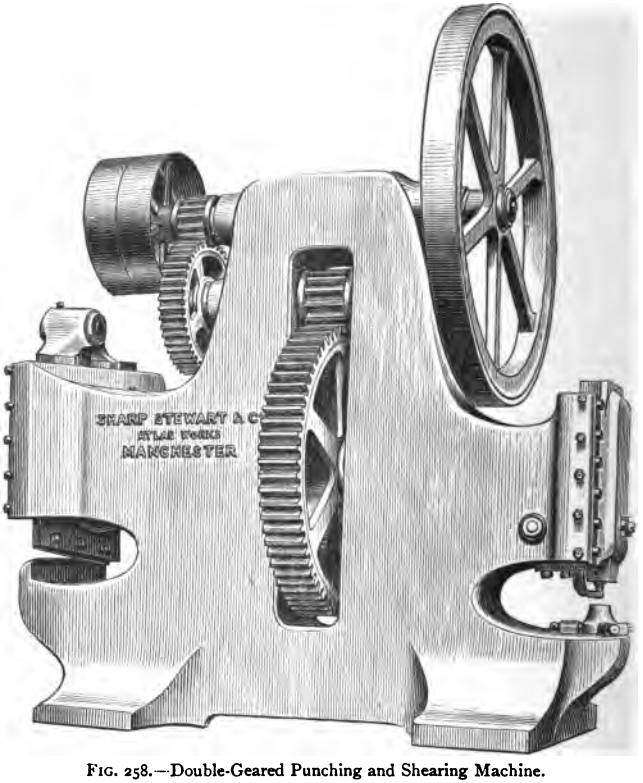

FIG. 258.—Double-Geared Punching and Shearing Machine.

the block, when in position, transmits the downward pressure of the lever to the slide, whence it passes to the punch. When, however, the block is withdrawn, the slide merely falls by its own weight, the punch descending and resting upon the work till it is again raised by the lever.

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But two other points remain to be noticed in Fig. 258, although they must not be supposed to be peculiar to this class of machine. One of these is the vertical plane of the shear-knives, which is not at right angles, but greatly inclined to the sides of the framing, and to the axis of the eccentric shaft. This is done with the object of enabling them to cross-cut bars or plates of any length, provided only that they are of small width. If placed square with the framing, the depth of the jaw would of course limit the distance from the end or edge of a plate at which the shears could operate, as already pointed out with reference to punching. The other point is, that the fit of the slides—on the freedom and steadiness of whose motion so much depends—can be adjusted by means of setting-up screws, five of which appear in the engraving at each end of the machine.

Some single-ended machines are also constructed on the eccentric principle, a single slide being then made to do double duty, having the punch attached to its lower, and the bottom shear-knife to its upper end.

Briefly stated, the requirements of a punching and, to some extent also, of a shearing machine are that the motion of the punch or knife shall be slow and uniform whilst cutting, quick during its return, and that the interval of rest shall bear as large a proportion as possible to the time occupied by the stroke. These, as we have already mentioned, are well fulfilled by a properly shaped cam and lever, whereas the eccentric gives us variable and similar motions during both the upward and the downward stroke, and commences its return immediately on arriving at the end of its traverse. The last, indeed, is a much more weighty objection to this application of the eccentric than might at first be supposed, since the accuracy of the position of holes punched in the ordinary manner (which are merely set out with a template by a kind of stencilling process) depends solely upon the plate being correctly placed by the workman, and the shorter the

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interval at his disposal for the purpose, the greater is the risk of error. The superiority of well-constructed lever machines in this respect may be gathered from the fact that on this system it has been found possible to keep the punch absolutely at rest during one-half of each revolution of the cam, thereby enabling the number of strokes in a given time to be made one-third greater than would be attainable in an eccentric machine, without curtailing the interval for placing the work.

To obtain more perfect correspondence between the holes in any two or more plates than is possible when the marks which denote their position are brought separately under the punch by hand, the late Mr. Henry Maudslay many years ago introduced a system of *Multiple-Punching*. The machines for this purpose, some of which have remained in use to the present time, bore a general resemblance to Fig. 255, the required motion, however, being imparted to the lever by a pair of toothed elliptical wheels, one of which occupied the position of the cam, and the other that of the roller. A series of punches were arranged in line at the lower end of the vertical slide, excessive strain upon the machine being prevented by making them of different lengths, so that they acted in succession, instead of at the same moment. A self-acting 'dividing table,' by which the plate was moved through the correct distance after each stroke of the machine, enabled greatly increased accuracy of 'pitch' (or distance from centre to centre) to be given to any series of holes. Single punching machines with self-acting tables are also made, and they appear to have much to recommend them. Other machines, with still greater capabilities and of correspondingly greater complication, have been devised, in some of which several rows of holes of equal pitch can be punched simultaneously; in others—or at least in one, the 'Jacquard Machine,' invented by Mr. R. Roberts of Manchester—any arbitrary arrangement of holes can be produced. But these are rarely to be

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met with, and therefore do not demand special notice here.

The Hydraulic System, which, as we have seen, is used for several kinds of hand-worked punches and shears, is applied also—and with excellent results—to large stationary punching and shearing machines, not at all inferior in power to those just described. For these, in common

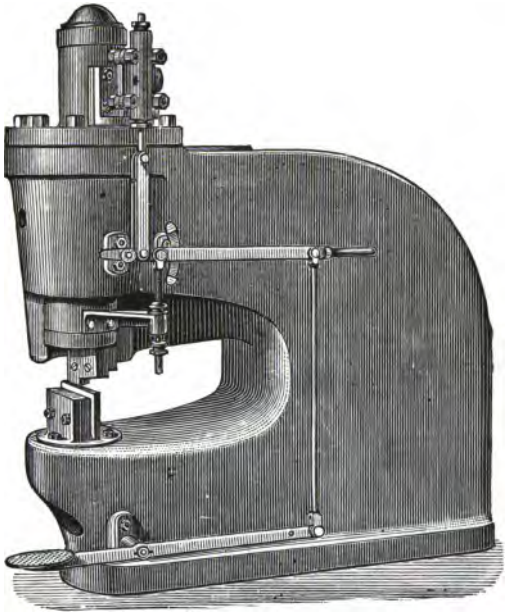

FIG. 259. – Hydraulic Shearing Machine.

with forging, riveting, and other machinery, in the action of which the time occupied has an important effect upon the result, the powerful sustained pressure thus obtainable seems to be eminently well adapted.

Fig. 259 shows a *Hydraulic Shearing Machine* with a clearness which almost renders an explanation of it

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unnecessary. The upper knife is fixed to the base of a ram working in a hydraulic cylinder. The starting lever, on being moved by hand or by the treadle, opens the inlet valve, admits water to the cylinder, and forces down the ram. At the end of the stroke—which can be varied as to length—the outlet valve is opened automatically, and the ram returns to its former position. A machine of this kind, being entirely independent of shafting and belts, can be placed if necessary at a great distance from the *accumulator* from which its power is drawn, with which a line of piping forms its only connection.

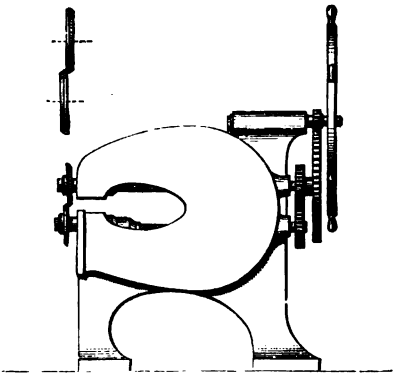

FIG. 260.—Circular Shears.

Special machines have been constructed for shearing the edges of boiler and other plates with greater speed and precision than is possible with the preceding machines, in which long cuts can only be produced by combining a number of short ones—the placing of the plate sufficiently correctly to ensure each one of the series forming part of the same straight line being no easy task. In these the length of the knives is made to exceed or at least to equal the length of the plate, which amounts in some instances to 10 feet and

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upwards. With such machines a single cut can be taken from the whole length of the plate, and in point of straightness it is of course far superior to any producible in those previously mentioned, in which 18 or 20 inches is the maximum length of the knives.

With the *Circular Shears*, invented by Mr. Roberts of Manchester, of which Fig. 260 is an example, cuts of unlimited length can be taken. The knives are made from circular discs of steel—as shown in the left-hand corner of the figure—and they are driven in opposite directions. The fact that they can be used for curved as well as for straight cuts frequently gives them the advantage over ordinary shears. In the manufacture of tubes, and for other purposes for which long lengths of sheet metal are required, they are very largely used, and they are also occasionally made for cutting plates up to as much as an inch in thickness. Where large quantities of sheet metal have to be cut into strips, a number of these revolving shears are mounted on one pair of spindles, so that a sheet in being passed between them is cut up at a single operation, the distance between the adjacent pairs of cutters regulating the width of the strips.

The capabilities of some of the punching and shearing machines in the above engravings are as follows :—

The hydraulic bear (Fig. 251) is capable of punching a hole $1\frac{1}{4}$ inch in diameter through a 1-inch plate, provided that its centre is not more than $1\frac{3}{4}$ inch from the edge. With the hydraulic shears (Fig. 253), bars of any length up to either 2 inches square, or 4 inches wide by $\frac{3}{4}$ of an inch thick, can be cut.

The lever machine (Fig. 255) is adapted for punching holes 1 inch in diameter through $\frac{7}{8}$-inch plate at any distance not exceeding $18\frac{1}{2}$ inches from the edge, and for shearing $\frac{7}{8}$-inch plates up to $17\frac{3}{4}$ inches from the edge.

Fig. 256, the double-lever machine, may be used for

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punching 1¼-inch holes, in ¾ inch plate, and for shearing plates ⅝ inch in thickness—the greatest practicable distance from the edge being 12 inches in each case.

The eccentric machine (Fig. 258) may be used for either punching or shearing plates 1¼ inch in thickness at a distance of 18 inches from their edges, provided that the punch does not exceed 1¼ inch in diameter.

The speed at which holes can be punched with machines such as these varies from 8 or 10 holes per minute for their heaviest work, to about 15 per minute when the work is light. This more than equals the performances of the most rapid of the other machines available for perforating iron plates, &c., viz. the multiple drilling machine. Nevertheless the tendency in modern engineering work—to which our remarks chiefly apply—is rather to diminish than to extend the use of punching machines, and, in many cases for which they would formerly have been preferred, to abandon them in favour of the slower but more accurate process of drilling.

Punching machinery is largely used in many manufactures which are outside our subject, some of which are, however, of great mechanical interest—as, for example, the process of perforating zinc, &c., with Larivière's machine, by which three rows of perforations, containing some hundreds of holes, are made simultaneously. For most purposes, indeed, for which it is necessary at a single operation to pierce holes which are not circular, recourse must be had to punches and dies, with which those of the most complex forms can be produced with nearly as much facility as can simple circles, ovals, or squares. Three examples of patterns thus produced in perforated zinc are given in Fig. 261.

The fact of the metal removed by a punch and die being in one solid piece or 'burr,' instead of being frittered away in shavings, is also turned to useful account in numberless manufacturing processes—'blanks' for coins, buttons, percussion caps, steel pens, the wheels and other portions of cheap clocks, and an endless variety of small metal objects

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of daily occurrence being made in this way. For some purposes, indeed, articles of much larger size are reduced to their proper shape in this manner. The axle-guards for railway carriages are a case in point, which, although they measure some 2 feet in height and exceed a foot in width, are cut at a single stroke from iron plates $\frac{3}{4}$ of an inch thick by a species of punching or shearing machine—for in such cases it becomes difficult to say under which head it should be included. But such processes are not usually in much favour in mechanical workshops. Still less are those in which a single hollowed cutting-punch is used, instead of the solid one with a corresponding die, which is the form employed in all the machines which we have been describing. The others are chiefly used for soft materials ; but a modification of them. in which two corresponding punches, with

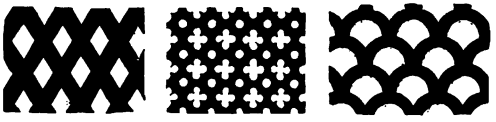

FIG. 261.—Perforated Patterns.

strong cutting edges, are forcibly driven from opposite sides into a sheet or thin plate of metal, has been of late years gaining ground in the manufacture of small articles, though we are not aware that it has yet extended into the practice of the engineer.

Before quitting the subject of punching machinery, one or two points in connection with the aforesaid dies and punches should be briefly noticed, inasmuch as the quality of the work performed by any punching machine is in the highest degree dependent upon the form and proportions of the punch and die. The use of the latter was explained in a former chapter (Chap. III.), and its general appearance and the means of adjusting it, so as to ensure its being in every instance concentric with the punch, will probably have been observed in the preceding engravings, although the

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attention of the reader has not before been directly called to it. In the hydraulic bear, for instance, a cast-steel ring forms the die (or 'bolster,' as it is not unfrequently called in the case of the smaller punching instruments), and it is kept concentric with the punch by being turned on the outside, so as to fit into a recess in the cast-iron jaw. But in the larger machines it is found more convenient to widen out the base of the die, and merely to let it rest upon the flat surface of the jaw, its position being regulated by three

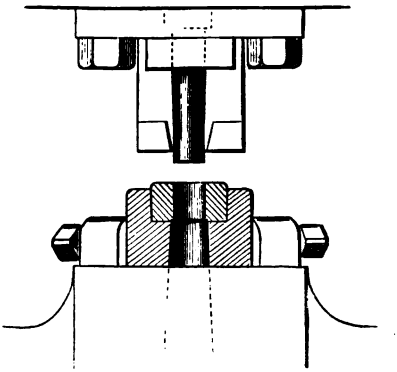

FIG. 262.—Section of Punch and Die.

or four screws working in fixed lugs, or by some other simple adjustment. Some makers transfer this adjustment to a separate bolster, into the upper part of which a small die is fitted, an arrangement which does not necessitate so great an expenditure of steel. But, whatever may be the external form of the die, a central perforation extends completely through it in all cases, and it is upon the internal proportions of this that its efficiency depends. The upper part of the aperture is cylindrical; the lower being tapered, as the accompanying section of a die and bolster (Fig. 262) shows. The parallel portion can then be sharpened by grinding its upper surface, as the angles become rounded by

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use, without altering the size of the hole, whilst the tapered continuation of the hole allows the burr which is punched out to fall freely through by its own weight—an opening being cast in the jaw just below the die, so that it drops out altogether clear of the machine.

For the actual size of the cylindrical portion of the die as compared with that of the punch, we can, however, give no definite rule. The evils more or less incidental to all

FIG. 263. – Punched Wrought-Iron Plate and Burr.

punched holes—namely, their form being conical instead of cylindrical, and their sides ragged instead of smooth—become greater with every proportionate increase in the size of the die. But, on the other hand, the reduction of the clearance to the lowest possible limit consistent with the free passage of the punch, though it reduces these evils, may perhaps increase the weakening of the surrounding metal, to which steel appears to be especially subject. Frequently the diameter of the aperture in the die is made to exceed by one-sixteenth part the diameter of the punch ; but, when it is required to give a more conical form to the holes produced, this difference is increased. In the generality of holes for rivets, and for most ordinary purposes, the conical form is a very great disadvantage, although cases do occur in which it is even beneficial—as, for instance, in the attach-

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ment of two plates only by means of rivets, when the hole in each plate has been punched outwards, each hole being in this way roughly countersunk. Another objection to punched holes is the rounding of their upper edges, which takes place on account of the compression of the iron before the punch begins to tear apart its fibres. This is especially the case with thick plates, and for this, even if for no other reason, they are much less fit subjects for punching than those which are thin. Fig. 263, which is taken from an ordinary wrought-iron plate, punched and subsequently split, shows both of these defects to some extent, and also the roughness of the sides of the punched hole and burr and of the edge of the plate, the latter having been cut with a shearing machine such as Fig. 258.

The action of punches has been recently investigated by M. Tresca in connection with the 'Flow of Solids,' and he has shown conclusively that even in the case of cold iron some of the metal flows from the burr into the surrounding portions, thus reducing its height to a certain and a calculable extent. His excellent papers on this subject, printed in the Transactions of the Institution of Mechanical Engineers, are well worthy of the attention of every one who is interested in the successful working of metals, either in the solid or the plastic condition.

With respect to the punch itself the usual practice is to use it only upon plates of which the thickness does not exceed its own diameter, though by taking special precautions small holes have been punched in wrought iron of which the thickness is as much as four times their diameter. The very slightly tapered form, shown in Fig. 262, is almost universally given, in order to diminish its friction against the sides of the hole. Inclining its face slightly (at from 3° to 5°), instead of making it horizontal, is by no means so prevalent a practice, though it has the advantage of bringing the pressure more gradually upon the machine than is the case when the work is commenced at all parts of the circum-

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ference at the same moment. With the same object it has been recommended to give a spiral form to the end of the punch, in the manner shown in Fig. 264. This, however, has the effect of spoiling the burr, which may sometimes be a disadvantage.

That the pressure is very considerable, even in punching holes of moderate size, may be gathered from the fact that it is found to be very nearly equal to the tensile strength of a bar, the area of whose cross section is the same as the area of the sides of the hole. Thus, in punching a hole 1 inch in diameter through a wrought-iron plate 1 inch in thickness, the pressure required was slightly more than 77 tons, which divided by 3·14 (the area of the sides of the hole)=24·6 tons per square inch, which corresponds very closely with the ultimate tensile strength of wrought iron of average quality. In some experiments by Mr. Hick of Bolton, this rule was found approximately to hold good, even when the diameter of the punch was increased to 8 inches, and the thickness of the plate to $3\frac{1}{2}$ inches, the pressure then required being 2,000 tons; and that it applies as well to shearing as to punching, provided that the edges of the knives are parallel, is also borne out by the facts given by Mr. Anderson in another volume of this series.[1]

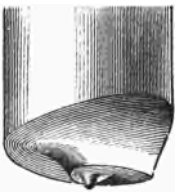

FIG. 264.
Spiral Punch.

In spite of its tapered form, a punch shows much reluctance to quit the hole it has made in any plate or bar, preferring to lift it during its own ascent, unless the weight be excessive. This tendency is resisted by affixing to the upper part of the jaw a 'guard' or 'puller-off,' of which the lower face is at least as low as the face of the punch when it is in its highest position. This puller-off is generally of

[1] *The Strength of Materials and Structures*, by John Anderson, C.E., &c.

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wrought iron, although a portion of the cast-iron framing is occasionally made to serve the purpose. Its position can be seen in each of the machines of which engravings have been given.

With regard to the knives of shearing machines, no very general rule seems to obtain—at least as far as the angle at which each knife is sharpened is concerned. In most instances the lower knife is ground to the same angle as the upper, but in some its edge is made square, that of the upper one being slightly acute. The actual angle which gives the best results varies with the hardness of the materials, 75° being about the minimum in the case of wrought iron and steel. Much greater uniformity of practice exists in the angle at which one edge of a pair of shear-knives is inclined to the other, by which they are made to bring a gradual instead of a sudden strain upon the machine. This angle is generally from 3° to 8°, according to the length of the blades, the whole of the obliquity being given to the upper knife, whether the construction of the machine demands that the motion should be imparted to that or to the lower one, of which the edge is horizontal. The lower knife thus forms a guide for the plate which is to be cut; for, by letting it rest fairly upon the edge, the workman is enabled without difficulty to keep it level in the direction of the cut. To assist him in also keeping it approximately level in the opposite direction, an adjustable finger, attached to the upper part of the framing, has been applied. It may be seen on the left-hand side of the machine represented in Fig. 256. With this it becomes impossible for the plate to be suddenly tilted up when the pressure comes upon it, or for the workman to raise its outer extremity to such an extent as to cause it to become jammed between the knives instead of being cut, from which breakage of the knives and damage to the machine occasionally result, and of which there is always some danger if the contact between the edges of the knives be imperfect.

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CHAPTER X.

ON THE DISTRIBUTION OF THE MOTIVE POWER TO MACHINE TOOLS.

THE Machine Tools at which we have glanced in the preceding pages, in almost all cases derive from some independent prime mover the motive power which enables them to perform their allotted tasks. One or two which have been mentioned—as, for instance, hydraulic punching and shearing machines—and many which are outside our subject—such as steam hammers—contain within themselves the motors by which they are driven, so that in their case the power can be directly applied through the medium of steam or water. But for others provision must be made for transmitting the power from the steam-engine, or other prime mover, to the tool in which it is to be applied ; the method almost invariably preferred for doing this when the distance is small—as in engineering workshops—being the employment of *Shafting* and *Belts*.

The diagram, Fig. 265, shows in plan and section a small portion of a workshop in which the power has to be laid on, as it were, from the engine E to the lathe L and the grindstone G.

In effecting this, the first step is to set up a *main line of shafting*, S, in any convenient position where the wall of the building, or the columns which support the roof (which are marked C, C in the present diagram) offer facilities for supporting it at suitable intervals. The strength of the shafting must, of course, be in proportion to the strains to which it will be subjected—and on this point the reader will do well to consult another volume of this series[1]—these being due, not only to the torsional stress caused by the trans-

[1] *The Strength of Materials and Structures*, by John Anderson, C.E.

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mission of the power, but also to the transverse pressure brought upon it by the *belting*, by which it receives its motion

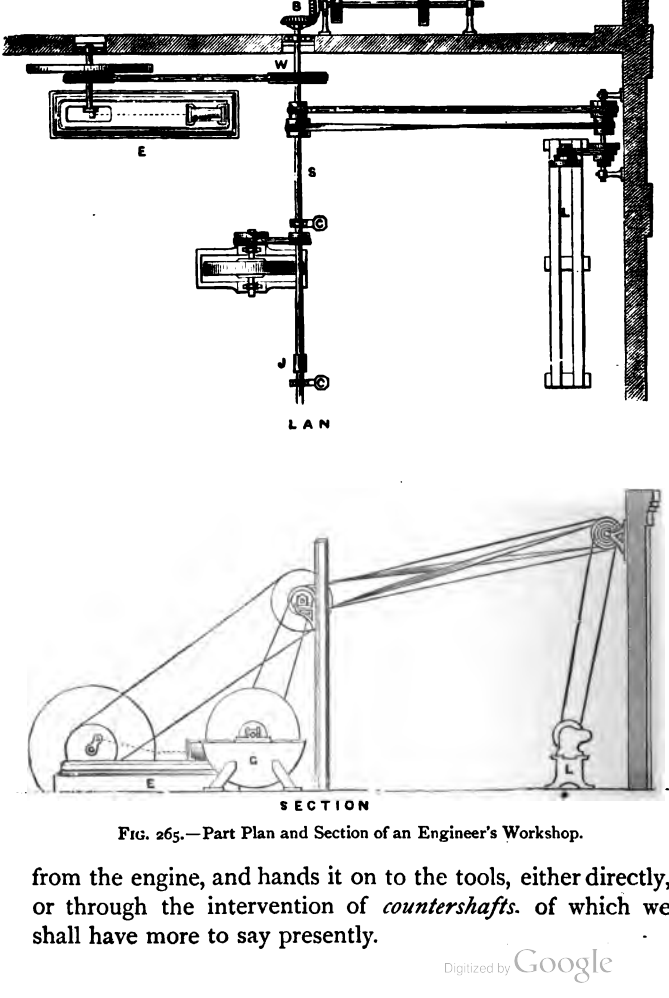

FIG. 265.—Part Plan and Section of an Engineer's Workshop.

from the engine, and hands it on to the tools, either directly, or through the intervention of *countershafts*. of which we shall have more to say presently.

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Where the length of the workshop is great—and it is generally desirable that it should be—the main shaft cannot be conveniently made in a single piece. Fig. 266 shows the best and simplest form of coupling—known as the *box coupling*—by which a series of comparatively short pieces of shafting can be connected together in such cases. The box or ring fits freely over the two ends, and is secured by a taper steel key driven tightly into a bed formed partly in the shafting and partly in the box. It will be seen that this arrangement enables any one length to be readily removed, if required, without disturbing its neighbours. For a joint of this kind to be efficient the coupling should always be placed near a bearing, as shown in the foregoing plan.

Occasionally, however, it is necessary to carry a line of shafting across some open space—as, for instance, from a

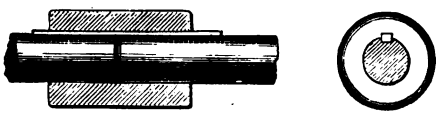

FIG. 266.—Box Coupling ($\frac{1}{12}$).

fitting-shop to a foundry—where it cannot conveniently be provided with intermediate support, so that the shaft must be made in one continuous length. In such cases much additional strength may be given to it by the system of *trussing*, shown in Fig. 268, a series of tie rods being so arranged that each in turn is thrown into tension as it is brought to the lowest point by the revolution of the shaft.

In the case of horizontal shafts (and the trussed shaft shown in the figure, as well as all the others which we shall have to speak of here, are horizontal), the bearing portions upon which they revolve are commonly called *journals*. These, when the shafting is either turned bright throughout or is 'cold rolled,' do not differ from other portions of it either in diameter or in truth of surface. When, however,

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the main portion of a shaft is left rough or 'black,' the turning down which is necessary at the bearing reduces the diameter of the journal, as shown at A, Fig. 267. The effect of this—when at least the length of the reduced portion does not exceed the width of the bearing which supports it—is to prevent any endlong motion on the part of the shaft, which of course is not required. But in a long length of shafting some slight motion in this direction must be possible, since the expansion or contraction which takes place with every variation in the temperature would cause undue pressure against one shoulder or the other at the points of support. It is, therefore, necessary to allow some liberty at all except one of these points, the travel at this one being prevented in the case of bright shafting by collars, either simply shrunk on, as at B, or forged out of the substance of the shaft itself, and turned with the internal angles rounded, as at C. The form which this journal frequently assumes when it occurs at the end of a line of shafting will be found in Fig. 274, one of the collars in this case being extended in length to form a boss, upon which either a drum or ...thed wheel may be keyed.

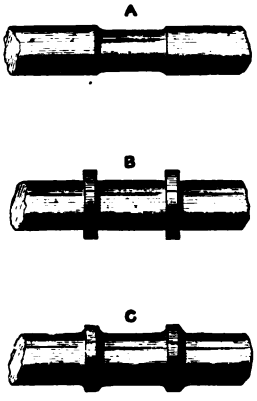

FIG. 267.—Journals.

FIG. 268.—Trussed Shaft ($\frac{1}{40}$).

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Our shafting is now coupled up, and at its extremities or at any convenient points in its length it is provided with journals resembling one or other of those just mentioned. We have now to support it, either from the cast-iron columns or the wall of the workshop, or, perhaps, from the beams of the roof. In either of the two former cases we make use of a cast-iron bracket, such as Fig. 269, varying its form to suit any special case. For giving a firm footing to this, our column should have upon it a projecting snug (s), on the upper surface of which a wedge (w) enables us

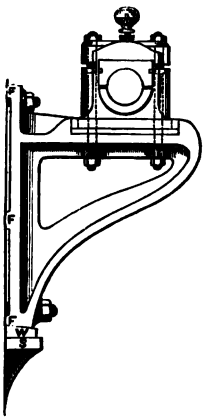

FIG. 269.—Bracket $\frac{1}{10}$).

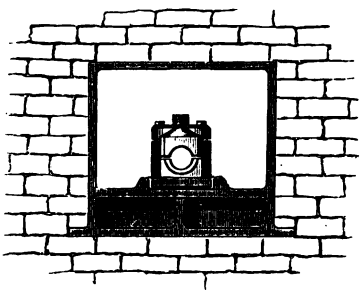

FIG. 270.—Wall-Box ($\frac{1}{24}$).

to adjust its height with accuracy. Two bolts only, which pass completely through the column, are then required for holding the bracket perfectly firm, *chipping fillets* (F, F, F), running across the back of it, providing us with a ready means of fitting it to the irregularities of the cast-iron surface. In a similar manner a bracket can be attached to a wall, a piece of hard-wood packing being then fitted to the much greater inequalities of the brickwork, and the bolts which are passed through it having large cast-iron discs or

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wall washers under their heads for the purpose of distributing the pressure.

In our engravings of the countershafts, Figs. 276 and 277 will be found examples of a *pendent bracket*, for the support of a shaft from an overhead beam, and of a *wall bracket*.

In its course a main line of shafting not unfrequently encounters a wall running in a different direction to its own, as at w, in the plan at the commencement of the present chapter. For supporting it under these conditions the arrangement known as a *Wall Box* is required. This—which is little more than a rectangular cast-iron frame of

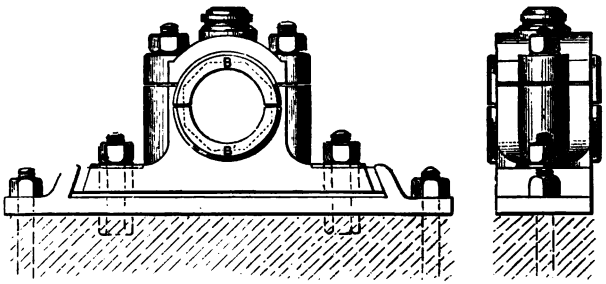

FIG. 271.—Plummer Block ($\frac{1}{8}$).

suitable depth—is secured by being built into the wall, as shown in the illustration on the preceding page (Fig. 270).

The shaft, however, does not rest directly upon any part of either the wall-box or the bracket. In each case a *Plummer Block* is provided for its reception, of which the object, when used either for the shafting of a workshop or for any of the very numerous other revolving shafts for which it is employed, is, first, to diminish as much as possible the friction between the moving surfaces ; secondly, to transfer the wear from the journal to the more easily renewable 'brasses' in which it runs ; and, thirdly, to afford the means of adjusting these as the wear takes place. In Fig. 271, a front and also a side view of a plummer block is represented,

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together with a portion of a *wall plate* upon which it may be conveniently fixed. With the exception of the upper and lower brasses B and B′ and the four bolts (two of which may be dispensed with by the arrangement shown in Fig. 269), the whole of the plummer block is of cast iron, its lateral adjustment being provided for by keys driven in between the extremities of its base and the snugs upon the wall plates. Similarly the height can be varied by increasing or reducing the thickness of wood packing below it. As the brasses become worn they can also be adjusted, the lower one by introducing thin 'liners' of tin plate, the upper by bringing down upon it the cast-iron cap; their inclination to revolve with the shafting being resisted by giving an octagonal form to the opening in the plummer block, or by some other convenient means.

For the 'brasses' of a plummer block some more durable mixture than yellow brass is generally employed. Gun metal is an improvement upon it, and phosphor bronze and some other recently invented alloys claim still greater superiority.

Babbitt's 'white metal' (consisting of tin and antimony) is a soft mixture which possesses great durability and gives excellent results in the way of reducing friction when applied to bearings, though it is less used for the bearings of shop shafting than for such as are of a more highly finished character. It is usually applied in one of two ways: either the brass is formed into a 'shell' and its inner surface is coated thinly and uniformly with the white metal, or a discontinuous coating is formed by filling with it a number of circular cavities with which the bearing surface of the brass is everywhere pitted.

Our main line of shafting may now be regarded as set up on its bearings, the several lengths being coupled together and any long unsupported portions being trussed. The amount of power lost in driving it will now greatly depend upon every bearing being properly lubricated.

The effect of lubrication upon a pair of smooth metal

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surfaces seems to be to prevent their coming into actual contact, by interposing between them a thin film of the oil or other substance employed. Whenever the lubricant is too thin, or the pressure tending to bring the surfaces together is too great for it, this film is pressed out, and some portions of them come into contact. They are then liable to adhere together so firmly that portions of one or other of them will be torn off before they will separate ; just as the two halves of a cleanly cut lead bullet or two polished surfaces of plate glass will unite inseparably. When this adhesion occurs between moving surfaces under a light pressure, 'cutting' or 'scoring' results, with a corresponding increase of friction ; whilst, if the pressure is considerable, their form may be entirely destroyed,—as an instance of which may be mentioned the behaviour of a dry railway axle when it 'seizes' the brass in which it is revolving.

Cylindrical gauges, such as Fig. 6, perhaps illustrate better than anything the value of lubrication. If a pair of these gauges are of exactly the same diameter, the external or plug gauge can only with great difficulty be made to enter the internal or collar gauge, as long as both of them are clean and dry. And if it be pressed into it cohesion sometimes takes place between their surfaces, and no available amount of force will separate them. But a single drop of fine oil enables the external to pass through the internal gauge easily and smoothly. If again a plug gauge is passed through a collar only one 10,000th part of an inch larger in diameter, it appears when dry to be so loose as scarcely to fit at all, but a drop of fine oil converts it into a fairly tight fit. With thicker oil a greater difference in the diameters would be required to produce a like result, so that in any special case in which it is very important to reduce to a minimum the friction of a journal in its bearing, the consistency of the lubricant which will be used should be taken into account in deciding upon the difference to be given to their diameters.

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Besides being of proper consistency and being unaffected in this respect by ordinary temperatures, it is important that lubricating oil should not be liable to thicken on exposure to the air, and that it should be free from the fatty acids capable of acting chemically on brass or copper, which are sometimes present. The following are the principal oils which are adapted for the general purposes of engineering workshops :—

Sperm Oil.—The best in ordinary use for machinery. For such as is accurately fitted and run at a high speed or under a light pressure, sperm oil is especially well suited, and it is to be regretted that its cost frequently causes inferior oils to be substituted for it.

Olive Oil.—For general machinery. Open to the objection of freezing readily.

Lard Oil.—Used as a substitute for sperm oil for light machinery. Freezes very readily and becomes very fluid with heat.

Rape Oil.—For heavy machinery. Not to be recommended for high speeds or light pressures. Clogs on exposure to air.

Palm Oil.—A compound of this with animal fats is used for railway axles under the name of palm railway grease.

Seal Oil.

Whale Oil.

Rangoon Oil.—This name, originally given to an oil derived from Burmese tar, is now applied to a similar product extracted in this country from American petroleum. It possesses valuable qualities in its absence of gumminess after exposure to air, freedom from action on brass and copper, and fluidity at low temperatures. These render it especially suitable for preserving metal work from oxidation, and have led to its recommendation and adoption by the War Office authorities for the preservation of small arms. For lubricating machinery, except under light pressures, it is rather deficient in 'body,' but this is sometimes corrected by adding to it a small percentage of some animal oil.

Under various fancy names other mineral oils (or mixtures mainly composed of mineral oils) are now obtainable, specially prepared for lubrication under different speeds and pressures. As economical substitutes for the more costly oils, some of these appear to have much in their favour. But the extent to which any particular oil possesses the good qualities mentioned above can be easily tested, and the practice of doing this is greatly to be recommended, especially in the case of mixtures, avowed or otherwise

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Next, as to the best methods of applying the oil; a problem by no means easy of solution in the case which we have been considering—namely, that of a line of shafting running in a series of bearings which are often in somewhat inaccessible positions. Some kind of apparatus capable of delivering a small and constant supply therefore becomes essential, so as to guard as much as possible against the power being uselessly expended in heating the bearings—which is the certain result of allowing the supply of lubricant to fail. A simple but not very effective plan is to cast a cup at the top of each plummer block, a small oil-hole running from the bottom of this through the cap and the upper brass to the journal. Such a cup appears in Fig. 271. In it is placed a piece of sponge, which readily sucks up the oil poured into the cup, and delivers it up again but slowly through the oil-hole.

As an improvement upon this, the *Syphon Lubricator* was introduced, in which the opening of the oil-hole is no longer at the bottom of the cup, but is brought almost or altogether up to a level with the top of it, by fixing into the aperture a short piece of tube, or otherwise. An ordinary cotton wick, of which one end is passed down the tube and oil-hole, and the other hangs over into the cup, then draws the oil over slowly and continuously, and delivers it into the bearing. For marine engines, and other machinery in which the motion is continuous for long periods, this method answers admirably; but for shafting, &c., which is running only for a portion of each day, the waste of oil during the idle hours is a great objection.

A much more ingenious arrangement is that known as Lieuvain's *Needle Lubricator*, one form of which is represented in Fig. 272. The oil is placed in a strong glass bottle, the neck of which is then stopped with a wooden plug. Through this plug passes the 'needle'—a piece of iron wire—fitting very loosely into the hole in the plug, which is bushed with brass. The orifice of the oil-hole in

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the bearing being enlarged to admit the outer end of the plug, the entire lubricator is then turned over into the position shown in the present engraving, and also in that of the bracket and plummer block (Fig. 269). The needle at once drops down upon the journal, the rotation of which imparts to it a slight but continual vibration, which causes the oil to creep slowly down into the bearing as long as the motion continues, but stops the supply directly it is brought to rest. A brass box with a glass 'skylight' is sometimes substituted for the bottle, but for shop shafting the latter is preferable, as the quantity of oil contained in it can be more readily perceived.

Returning now to the general question of the distribution of the power, let us examine the arrangement for drawing off from the main stream the successive portions of it required for serving the various tools in its neighbourhood. For many of them it suffices to place opposite to them upon the main shaft a *Driving Drum*, such as that shown in the left-hand portion of Fig. 273. A leather belt, running round the periphery of this and round a similar drum upon the machine which is to be driven, enables the power to be delivered with but trifling loss at any point within about 30 feet of the line of shafting. In the plan, Fig. 265, the grindstone G is driven in this way—'direct' as it is called—thus receiving from the main shafting whatever power it may require, just as that in turn obtained it from the crank-shaft of the engine. The reader is now too familiar with the system of 'keying' to be for a moment at a loss as to how the drum in the engraving is intended to be attached to the shaft, but a plan sometimes employed in preference—as it involves less costly fitting—is to bore out the boss to a

FIG. 272.—Needle Lubricator (⅛).

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larger size than the shaft requires, and to drive from each side into the annular space a split conical bush.

To diminish the risk of fracture in cooling, to which the edges of such thin castings are liable, the arms are frequently curved, as indicated by the dotted lines, instead of being made radial. The other drum shown in Fig. 273 is known as a *Split drum*, and it possesses this advantage, that it can be attached at any point in a long line of shafting without necessitating its removal. By so proportioning the size of the aperture through the boss that the act of bolting together the two halves of the drum causes it to clip the shaft sufficiently firmly, the key may often be dispensed with. Drums

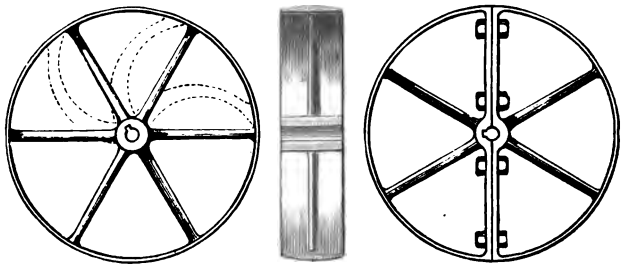

FIG. 273.—Driving Drums.

of both these kinds are now frequently made of wrought iron.

The slightly convex form of the face which appears in the section might perhaps be thought to be ill adapted for preventing a belt from running off at the edges. It is found, however, to be better than any other, and is the form almost invariably given to a 'single' drum, or one upon which one belt only is to run without change of position. The width of a drum of this kind should be about one-fourth greater than that of its belt.

When the duties of a belt and drum are exceptionally heavy, as in driving a long line of shafting, or when it is necessary to affix to it a toothed wheel for the same purpose,

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it is advisable to enlarge the shaft at the point of attachment, and to have recourse to keying in the ordinary way, as shown at A, Fig. 274. Other unsplit drums can still be introduced upon the shaft, and be secured, either with the coned bushes mentioned above, or by 'staking' them, as shown at B.

For the belting, by which the last stage of the connection between the prime mover and the several machine-tools is established, various materials—such as canvas and india-rubber, gutta-percha, Manilla and other vegetable fibres—have been employed ; but for this purpose it may be safely asserted that there is nothing like good leather.

The size of a leather belt must of course depend upon the amount of power which has to be transmitted by it, or

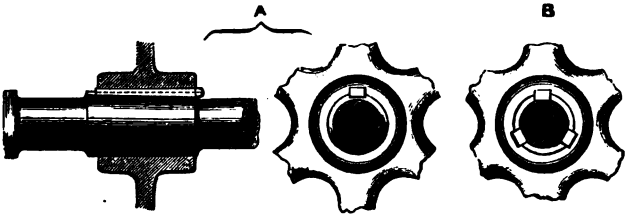

FIG. 74.—Methods of Keying and Staking.

rather by its 'leading side,' for one half of it only—namely, that which is moving towards the driving-shaft—is in action at once, and it is along this only, and not along the 'following side,' that the power is, as it were, flowing. The greatest tension (or pull) which can be brought upon this side by the action of the machine, together with that upon the following side due to the stretching of the belt over the drums, furnishes us with a guide as to the sectional area of leather required in each case ; 40 lbs. per inch in width for each eighth of an inch in thickness being about the greatest strain at which it may be worked with safety. But as the thickness must depend upon that of the hides from which the belting is cut, and this varies only from about $\frac{1}{6}$th to $\frac{1}{4}$th of

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an inch, it becomes little more than a question of what width is to be employed, and whether the belt shall be single or double.

Examples of the joints used in building up belts of each kind from any requisite number of short strips are given in the diagram (Fig. 275); for the strips being cut straight, cannot, of course, exceed the length of the hide which yields them. Another kind—'ridged belting'—is also there represented, the object of the ridges being to prevent undue stretching of the edges, a defect to which wide single belts

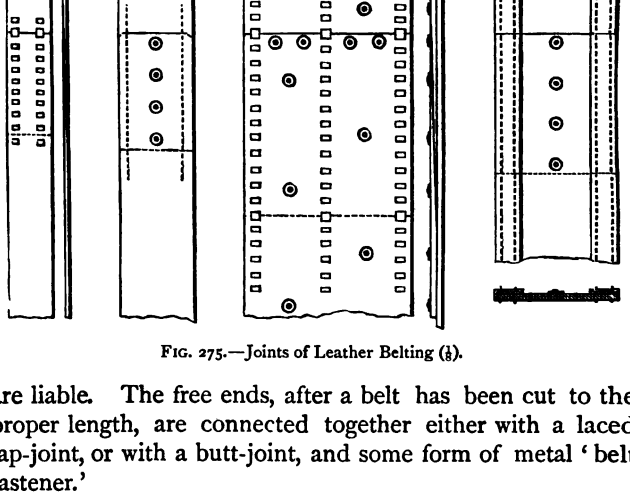

FIG. 275.—Joints of Leather Belting ($\frac{1}{8}$).

are liable. The free ends, after a belt has been cut to the proper length, are connected together either with a laced lap-joint, or with a butt-joint, and some form of metal 'belt fastener.'

We have now the means of conveying the requisite power to our machine-tools, and as far as the speed and the direction at which they are driven are concerned, we can vary the first within considerable limits by making the driving-drum upon the shafting larger than that upon the machine (or *vice versâ*), and the second by either crossing

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or not crossing the belt in its passage from one to the other. With the simple addition of a 'loose' or 'idle' pulley, to enable the tool to be brought to a stand without stopping the main shafting or throwing off the strap, this indeed is sufficient in the case of many machines, as, for instance, those for punching and shearing; but when it is required either to have the means of readily adjusting the speed or changing the direction, an intermediate or *counter-shaft* becomes necessary. An example of one of these in its simplest form—ready adjustment of the speed only being its object—will be found in the drilling machine represented in Fig. 207, where it is attached to the lower part of the framing. They are, however, more usually placed overhead, as in the case of the lathe L in Fig. 265, since belts cannot be

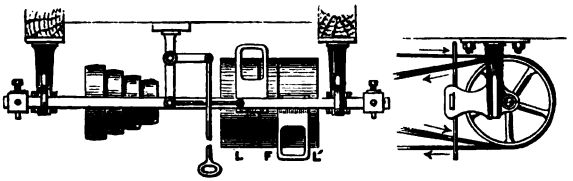

FIG. 276.—Countershaft for Reversing ($\frac{1}{11}$).

worked with advantage when the distance between two shafts is very small. But when once we are provided with a countershaft, then, by merely increasing the width of its loose pulley (L), and introducing another one (L'), in the manner shown in the annexed diagram (Fig. 276)—a second drum, or one of greater width being also placed upon the main shaft—we are enabled to drive it at will, either in the same or the reverse direction. For by passing over the loose pulleys two separate belts, one of which is crossed and the other not crossed, they are made to revolve constantly in opposite directions; and although neither of these is capable of imparting motion to the countershaft, it can be instantly thrown into action by transferring one or other of the belts

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to the narrow fast pulley between them. With this object each belt is made to pass through a 'fork' just before it reaches its pulley, and these being attached to a sliding bar, which by sufficiently obvious means can be moved either to one side or the other, enable the counter-shaft—and with it the lathe or other instrument driven by it—to be set in motion either backwards or forwards, or to be brought to rest by the mere movement of a handle.

A slight further alteration renders the speed unequal in the two directions, and gives to the counter-shaft the means of providing a screw-cutting lathe, or any other tool, with a 'quick return.' The pulleys which give the backward or return motion are then made of much smaller diameter than the others, as in Fig. 277, whilst the size of the drum

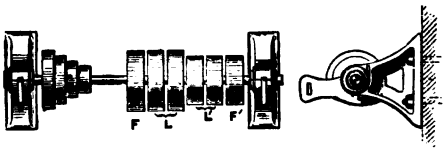

FIG. 277.—Countershaft for Quick Return ($\frac{3}{16}$).

on the shafting from which the crossed belt passes to them is correspondingly increased. In the diagram the two fast pulleys are marked F and F', one of each size being now required, and the loose pulleys are indicated by the letters L and L'. Whether each of these is made in two parts, as in the figure, or in one, as shown in Fig. 276, is only a question of convenience in manufacture.

The determination of the relative diameters of the drums and pulleys which will be required for driving any particular machine presents no difficulty, provided that we know, in the first place, the speed at which the main shafting revolves, and, secondly, that which it is most advantageous to impart to the tool or the work. Their actual sizes are limited, on the one hand by the circumstance that when the driving

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drum is very large its weight becomes objectionable, and, on the other, that when a pulley is very small its surface is insufficient to prevent the belt from slipping, unless, at least, the speed be very high, or the power transmitted by it be inconsiderable.

The former of these—namely, the speed of the shafting—is assumed by engineers' tool-makers to be 100 revolutions in a minute, and the driving apparatus ordinarily supplied with any machine-tool is therefore so proportioned as to give such an increase or reduction of this speed as shall be suitable for the work to be performed by it. Cone pulleys, to which attention has been already called on more than one occasion, are also introduced whenever it is necessary to have the power of varying the rate of speed, and that this is necessary in the case of such instruments as the lathe will be easily imagined. For not only does the variable diameter of the work produce great differences in the length of it upon which the tool is made to act in any given space of time, but the different degrees of hardness of the materials which have to be treated make it exceedingly desirable to have the means of varying the motion accordingly.

The following are the approximate speeds in feet per minute, for metal turning and planing, but they are subject to modification according to the depth of the cut, which it is the tendency of modern practice to increase :—Steel, 12 ft. ; cast iron, 18 ft. ; brass, 20 ft. ; wrought iron, 24 ft. Dividing these by the number of feet in the circumference of any piece of work which is to be turned, we of course obtain the number of revolutions at which it is desirable that the mandril should be driven. With wood the surface speed per minute may be sometimes as high as 2,000 feet (and even 3,000 feet per minute when the tool, instead of the work, receives the motion), and it is probable that those given above for metal might be much increased but for the great heat produced, which endangers the temper of the tool.

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In order to assist in carrying off the heat, and also to reduce the friction between the face of the tool and the newly-cut shaving, copious lubrication is desirable in working steel or wrought iron in the lathe or planing-machine, although for cast iron and brass, of which the shavings break up instead of curling, the same necessity does not exist, and these are treated in a dry state. The ordinary lubricant in such cases is a mixture of soap and water, or a weak solution of common (carbonate of) soda may be used, since this likewise restrains the rusting action of the water. But coarse kinds of oil, such as whale and seal oil, or mineral oils from petroleum, &c., are preferred for some purposes,—amongst which may be mentioned screw-cutting by means of taps and dies.

FIG. 278. Crossed Shafts.

Returning for a few moments to the plan in Fig. 265, it should be noticed that the main shafting does not always run in a single straight line throughout the workshop, nor even in two or more parallel lines, although this last is by no means an uncommon arrangement. At the top of the figure is a cross-shaft, at right angles to the main shaft (S), from which the motion has to be imparted to it. As there shown, this is done by means of a pair of bevil wheels (B), but when a small amount of power only is to be transferred from one shaft to another running in a different direction, a leather belt may be employed, as in Fig. 278. For this, however, there must be considerable difference of level between the shafts.

It is generally desirable to have the power of disconnecting some portion of a line of shafting in a more rapid manner than by taking off a coupling. This can be done by means of what are known as *Clutches*, which often consist merely of a pair of circular boxes with corresponding

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projections cast upon their adjacent faces. These are placed upon the shafting at the point of junction between two of its lengths, and are so arranged that one can be slid on a feather so as to be either in or out of contact with the other. The shock with which the revolving box engages with that which is at rest constitutes the chief objection to them. *Friction Clutches*, which obviate this, have been arranged in various ways, one of the simplest being the *Cone Clutch*, Fig. 279. The connection is established by pressing one half, which has an external conical surface, into the other, which is hollowed and coned internally, the friction between these surfaces being sufficient to cause them to revolve together. In this there is a slight waste of power, on account of the friction of the collar which runs in the groove G, by which, through the medium of a lever attached to it, the sliding cone is continually being pressed into the hollow whilst the clutch is in action.

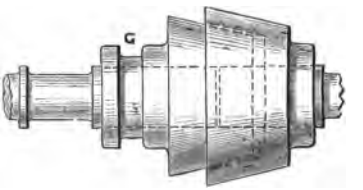

FIG. 279.—Cone Clutch.

In *Weston's Friction Clutch*, the surfaces from which the friction is obtained are much larger in area, being afforded by the flat sides of a series of discs, which are made alternately of iron and elm-wood. In the section of this Clutch, Fig. 280, the latter are marked *a*, and revolve with the shaft A, whilst the former are marked *b*, and are keyed to the shaft B. As here arranged, the clutch is kept always in gear by a series of spiral springs, which are drawn back,

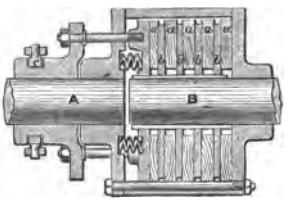

FIG. 280.
Weston's Friction Clutch ($\frac{1}{12}$).

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when the connection is to be broken, by a lever acting upon the collar *c*.

Several other friction clutches have also been devised, but a description of them would unduly extend the limits of the present chapter. Some of them may perhaps be advantageously substituted for either of those figured above, whilst others—such as the 'hydraulic reversing clutch' for rolling mills—have been made for one special purpose, and are not generally applicable.

The points in the main shafting at which clutches can be most advantageously introduced, and by consequence the extent to which the wear and tear, and the absorption of power in such portions as would otherwise be 'running idle,' may be saved—for no system of transmitting power with which we are acquainted is entirely free from leakage—must depend upon the general arrangement of the workshop and the disposition of the tools which it contains. For these no absolute rules can be laid down, since each case must in great measure be governed by its own special requirements. To give to the subject the best possible attention in the first instance, will be found in the long run to be the surest economy.

Such, briefly stated, are the main points of interest in connection with shop shafts and belting. These, however, although the commonest, are by no means the only available method of distributing the power to machine-tools. Steam-hammers, for instance, in common with many other tools which do not come within the subject of the present volume, contain within themselves the prime movers by which they are driven, and in many such cases the steam itself becomes the carrier of the power, and is laid on direct, instead of being first used to produce the rotary motion which is necessary for such tools as lathes and drilling machines.

Or *Compressed Air* may be used as the carrier; and since, unlike steam, its efficiency does not depend upon the maintenance of a high temperature, it can be conveyed for

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greater distances with a smaller percentage of loss, though it is not free from other drawbacks.

The *Hydraulic System* too is very largely used for the distribution of power, and for some purposes it possesses great advantages, though it has not yet fulfilled the exaggerated expectations formed of it by Joseph Bramah. The basis of the system is the employment of water confined under a high pressure, and the power conveyed in this way suffers but little loss even when the distance traversed is considerable. It is noticeable that in connection with this system there has been made a distinct advance towards one of the most practically important of all mechanical problems—that of the storage of power. By availing ourselves of the hydrostatic pressure of water stored at high elevations, or by storing it under pressure artificially produced by means of an *Accumulator*, we can utilise sources of power which without storage would be quite insufficient for a given purpose. Thus a small donkey-engine, employed for an hour in pumping water into an accumulator, may be made to lift in a fraction of a minute with a hydraulic crane a weight with which its unstored power would have been quite incompetent to deal.

Our ideas, however, both as to the transmission and the storage of power, seem destined to be revolutionised by a system which has quite recently entered the field as a rival to the above, viz. Electricity. The facility which it bids fair to afford for laying on power to great distances, either from centres at which it may be generated on a large scale by the combustion of coal with a degree of economy now unattainable in practice, or by utilising natural forces—such as falling water or the tidal wave—which are now suffered to run to waste, renders it probable that electricity will hereafter, to a great extent, supersede the steam-engines and other motors with which we are now familiar, and will change completely the aspect of our workshop appliances.

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CHAPTER XI.

ON TOOL STEEL AND ITS TREATMENT.

IN the preceding pages some little space has already been devoted to the subject of the sharpening of steel cutting-tools, more especially the 'grinding' and 'setting' of edge-tools for wood, and the filing of hand-saws. But there remains a large class of metal tools and cutters to which the original forms which they gradually lose in use cannot be restored by these simple means.

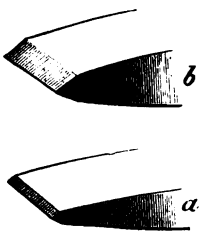

FIG. 281.—Edge of Chisel before and after 'fettling.'

A chipping-chisel, for instance, may be sharpened a certain number of times upon an ordinary grindstone, but at each successive grinding the ground facets become larger, and the time spent in grinding them increased. Sooner or later, therefore, recourse must be had to 'fettling' it (*i.e.* drawing out, hardening, and tempering it), in order to bring back the edge from a condition resembling *b* in the annexed sketch (Fig. 281) to its original condition *a*. For doing this successfully, it is imperative to know something of the nature of *steel*, and of the various ways in which it is affected by heat.

Any one commencing the study of this peculiar metal at once encounters a difficulty in limiting the term, as it has of late years been made to include a whole series of compounds, many of which are more closely allied to wrought iron than

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to the high-class steels suitable for edge tools to which it was formerly confined. This difficulty must continue till the various kinds of 'homogeneous iron,' 'ingot metal,' or 'mild steel' have been provided with properly descriptive names—which it is to be hoped they soon may be. These, however, will not be included in the term 'steel,' as used for our present purpose.

It is now pretty generally agreed that perfect steel would consist of pure iron and carbon only; and that under that condition—unattainable in practice—its quality, from a chemist's point of view, would depend solely upon the amount of carbon, which might then be present in any proportion up to about 30 parts in 1,000. In the steels (*i.e.* the tool steels) of commerce, even in those which can claim at all to approximate to this ideal, the higher of these proportions is not nearly reached, the range of carbon being only from about 6 to something like 20 parts in 1,000. In these, although some other substances are always present, it is the amount of carbon which chiefly determines the suitability of a sample of steel for any particular purpose, and also the treatment to which it may be subjected, especially when heated. The other substances which occur as impurities (derived originally either from the ore or from the fuel) are principally sulphur, phosphorus, and silicon; and their effects, roughly stated, are as follows:—

Sulphur tends to render steel 'red-short,' or brittle when heated.

Phosphorus 'cold-short,' or brittle when cold.

Silicon both red and cold short.

But the effect of one of them may be modified by the presence of another; also by the proportion of carbon, and by the presence of some other substances—notably manganese,—which itself greatly influences the admissible amount of carbon. Both silicon and manganese are indeed sometimes introduced purposely in the process of steel manufacture, to serve as correctives of other impurities. But they

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must themselves be regarded as impurities with which it would be a great advantage to be able to dispense. The subject of the chemical composition of commercial steel is altogether one of great complexity and difficulty, and it is a study for the steel maker rather than for the steel user. Very small differences in the percentage of the above and of some other substances may greatly influence the character of the steel produced. Moreover, the property of absorbing some of them in the gaseous state, which hot steel is now proved to possess, renders its original composition liable to change whenever it is afterwards heated in contact with ordinary fuel, which is never wholly free from impurities.

The strength and endurance of steel, however, are very largely dependent upon its physical condition, so that a mere knowledge of its chemical composition is quite insufficient as a guide to its fitness for any particular purpose. To judge of this condition, it is a common practice to 'nick' and break a bar before heating it, and to observe the fracture; which, if it presents a fine uniform grain and 'silky' texture, and a conchoidal (*i.e.* shell-like) form, is taken to indicate good steel; absence of these qualities, on the other hand, being considered an indication of inferiority. But the evidence which this affords is of a negative kind only, even when due precautions are taken in applying the test, and in inexperienced hands the best of steel may very easily become unrecognisable from its fracture. Closeness of grain, under any circumstances, is not a certain proof of goodness. And the appearance of the fracture is greatly influenced by the hardness or softness of the bar under trial, by the heat at which it has been finished under the hammer or rolls, by the extent of the nicking, and by the suddenness with which it has been broken.

On the whole, therefore, in order to procure the steel which is most suitable for any particular class of tools, the best course is to apply to a reliable manufacturer, stating

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exactly the purpose for which it is required, and paying a sufficient price. For the fact should be borne in mind that low-priced steel is often much more costly in use than that which is higher in price, but possesses more lasting resistance to wear.

The selection of steel of proper 'quality' and 'temper' will then rest with the manufacturer, who—it should be explained—by the term 'temper' expresses the degree of carbonization of any particular steel, in which sense it has no connection with the process of 'tempering' presently to be described. The notes given below, in a tabular form for clearness' sake, show roughly the proportion of combined carbon in crucible cast-steel corresponding to different 'tempers,' with examples of the uses to which it may be subjected without injury in working. But in ordering steel, such general information should never be substituted for full particulars, without which the maker can never be sure of supplying that which will best meet the requirements of the case.

Crucible Cast Steel.

	Mild temper. Easily weldable	Moderate temper. Weldable	High temper. Difficult to weld	Highest ordinary temper
Approximate Carbon in parts per thousand	6 to 8	8½ to 10½	11 to 13	15
Suitable for	Smiths' tools	Punches, taps, chipping chisels, &c.	Wood tools, drills and cutting tools for iron and steel.	Tools for chilled iron
Heat for working	Bright red	Blood red to bright red	Blood red to full red	Blood red

Crucible steel of still higher temper, containing sometimes as much as 20 parts of carbon in 1,000, is made for some

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special purposes, but it is not suited for ordinary use, being difficult to work, and almost impossible to weld. For each addition to the proportion of carbon lowers the melting point of the steel, and causes it to pass more quickly from the solid to the fluid condition ; the duration of plastic state, to which the possibility of forging and welding iron and its compounds is mainly due, being thus proportionately reduced.

Suitable steel having been obtained, the quality of a tool made from it will depend mainly upon the skill with which it is treated, and upon the observance of certain precautions in heating it, not only in the first instance, but at every subsequent heating. Before going into particulars as to these precautions, it will be well to give a consecutive outline of the process by which a tool or cutter may either be made from the original bar of steel, or be reformed after being worn or broken.

The working temperature of the particular steel having been ascertained, if necessary by trial, the tool is brought as nearly as possible to the required shape by forging (itself a wide subject, and one altogether beyond the scope of the present volume) ; especial care being taken that the cutting edge shall be well worked under the hammer.

The steel will now be quite soft, so that whatever grinding or filing up is required can be easily done ; and in this connection the couplet, stated by Moxon upwards of two hundred years ago to have been an old and familiar one in his day, should be borne in mind :—

> He that will a good edge win,
> Must forge thick and grind thin.

If by either filing or grinding the outer skin is removed from any portion of the tool, it is desirable to remove it from all the portions which are to be subjected to the next process, viz. hardening.

To *harden* it, the tool is again raised to a proper heat,

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ascertainable by trial, and it is then suddenly cooled, which is generally done by plunging it into a trough of water. This, however, gives too great hardness, as no steel can be very hard without being also brittle, to a greater or less degree according to its composition. It is therefore necessary to *temper* it by careful re-heating up to a certain definite point, by which means the tenacity can be sufficiently restored without sacrificing the hardness to too great an extent. This tempering, or 'letting down the temper,' is a delicate process, which is happily much facilitated by the fact that when brightened steel is heated, the superficial oxidation which takes place in the air is accompanied by a constantly varying coloration of the surface, as the temperature rises from about 430° to 600° Fahrenheit. The colours which it successively acquires, and their corresponding temperatures, will be found in the Appendix. On brightening a portion of the surface after hardening, it becomes possible, therefore, by observing these colours, to arrest the heating at the proper point, and so to bring the tool exactly to the desired temper. The particular shade which corresponds with this temper will, however, require to be ascertained by trial wherever the natural hardness of the steel under treatment is unknown.

In practice the above process is generally shortened by confining the hardening to the neighbourhood of the cutting edge, and obtaining from the uncooled portion of the tool the heat required for tempering it. A chipping chisel (to revert to the former example) has only its cutting end completely cooled by quenching in the water-trough; and on this hardened end—brightened by rubbing it on a piece of gritstone—the characteristic colours gradually appear, travelling onwards in succession as the heat returns by conduction from the stem. As soon as the colour corresponding to the required temper has reached the cutting edge, the entire tool may be cooled.

The treatment will thus be seen to have three distinct

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stages. At each stage there exist some precautions which are essential to success, and others which may conduce to it in difficult cases; amongst the most useful of each kind being the following:—

In *heating* steel, whether for working it, annealing it, or for any other purpose—

Use the purest obtainable fuel. Charcoal is far superior to coal or coal-gas or coke, but the scarcity of timber in this country unhappily renders its price prohibitory for ordinary work, except on a small scale, when it should always have the preference. Whenever recourse must be had to coal or one of its products, it should be of a kind as free as possible from sulphur, which is present in much of our British coal in so large a proportion as to render it entirely unfit for smiths' use, even in the working of iron.

Heat the mass uniformly throughout, or, at least, heat uniformly the portion of it which is to be treated. Unequal heating is a fruitful source of the difficulties experienced in the working of steel, as forging it when the outside is either much hotter or much cooler than the inside results in unsoundness. In order to secure sufficiency and uniformity in the heating of large and thick masses, it is recommended to allow ample time for the heat to penetrate, applying the blast for a portion of this time only, and repeatedly altering the position of the steel whilst it is in the fire.

Small tools and cutters, especially such as have thin edges or projecting parts which would be very liable to be made too hot, may sometimes be advantageously heated in iron tubes or boxes. In these they can be surrounded with coarsely-powdered charcoal, which assists in rendering the heating uniform, at the same time preserving the steel from contact with the burning fuel, and preventing any loss of the carbon contained in it. Clay or loam may also be used as a protective coating in some cases; or a bath of red-hot lead can be employed as the source of heat.

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Re-heat as few times as possible. The quality of steel is deteriorated by re-heating, especially with impure fuel.

Avoid 'soaking' in the fire when once the full temperature has been reached. Steel should be worked immediately on becoming sufficiently hot throughout. Long soaking, even at a low heat, is very prejudicial to it.

Carefully avoid over-heating. Different kinds of steel vary greatly as to the degree of heat which they will bear. In general, the higher the proportion of carbon, the lower must be the working heat. Tool steel should not be made so hot as to show a scale upon its surface. The quality of steel which has been accidentally over-heated, if it has been for a short time and to a small extent only, can be partly restored by being well hammered—at first with light blows.

If over-heating is carried to a further stage, steel becomes 'burnt,' and it is then incurably spoilt. Brilliant sparks are an indication of burning. On attempting to work burnt steel, it will be found to have become 'red short,' and it will fall to pieces under the hammer. When good steel shows a tendency to do this, it may generally be taken as a proof that it has been over-heated.

In *hardening*—

Heat the steel no more than sufficiently to give it full hardness when quenched. There appears to be always a definite point of temperature below which sudden cooling is incapable of producing hardness. But it varies considerably in different steels, being highest in those in which the proportion of carbon is least. In highly carbonized steel, for which a comparatively low heat suffices, and in which the risks of hardening are the greatest, it is especially desirable to exceed this temperature as little as possible. It may be easily found by trial, a small sample of the steel being first quenched at a blood-red heat and tested with a saw-file. If found to be incapable of resisting the file-teeth, it is a proof that the hardening point has not been

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reached, and the quenching must be repeated after heating to a rather higher temperature than before. But beyond this point additional heat does not give additional hardness; and, provided that the uniformity in the heating already insisted upon be secured, it appears probable that the difficulties inseparable from the hardening process would be often materially reduced if stricter attention was paid to avoiding any excess of heat at this stage.

Cracks, known as 'water-cracks,' often make their appearance on quenching hot steel, and entail the loss of all the labour which has previously been bestowed upon it. Amongst the recognised causes which give rise to them in steel of good quality are—(1) Over-heating; (2) Unequal heating, especially if the outside of the steel be made hotter than the inside; (3) Previous soaking in the fire; (4) Plunging the steel for a portion of its length only, and keeping it still instead of constantly in motion in the water whilst cooling. Another cause of water-cracking, even when these four have been studiously avoided, is believed by the writer to be the existence of a local weakening of the cohesion between that portion of a bar of steel to which the heating has extended sufficiently to alter its structure, and the remainder which has not been so altered.

Loss of shape in quenching is another source of trouble, even when the state of strain which causes it does not produce actual fracture. The danger of this occurring often prevents the softening and re-hardening properties of steel from being taken advantage of when they otherwise would be; as, for instance, in repairing tools and cutters which are complicated in form, or which require a high degree of accuracy. The precautions against it must vary so greatly according to circumstances, that examples, which would carry us beyond our space, would be necessary for explaining them. But it may be said generally that sharp corners and internal angles are a fertile source of both water-cracks and distortion, and they should always be avoided if possible.

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The treatment suitable to several special cases will be found described in the useful book on Steel,[1] in which Mr. Ede has given the conclusions to which he has been led by long practical experience. Equal quenching of all parts of the steel which are to be equally hardened is the main point to be aimed at, and a little consideration will generally suggest some suitable means by which this may be fairly well secured. Thus, in quenching a tool of which one portion is thick and another thin, the thickest part should generally be the first to enter the water.

In the same work will be found some information respecting the use of salt solutions, &c., for hardening. Steel-workers sometimes add mysterious preparations to the water, under the name of 'physic,' and attribute to them wonderful properties; but for the ordinary purposes of an engineer's workshop an ample supply of clean water generally suffices. But authorities for the most part agree that the water should not be very cold, that its surface should be free from grease, which would prevent it from acting uniformly on the steel plunged into it, and that water which has been boiled or has been for some time in use is preferable to fresh water from which the air has not been expelled.

Hardened steel which has not been tempered or 'let down' will resist a saw-file, and will readily scratch glass. If found to be too soft to do this, it should, as already stated, be made slightly hotter than before and again quenched, as tempering is of course impossible unless the steel is hard.

In *tempering*—

Take sufficient time. The slower and the more uniformly the colours appear, the better is the result likely to be.

Quenching after tempering is unnecessary if the heat is raised only to a sufficient point to give the desired colour. In the case of small tools this may be easily done by laying them on a bar of hot iron.

[1] *The Management of Steel*, by George Ede. London, 1866.

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The pale straw colour which is the first to appear cannot be easily seen, except on comparison with an unheated piece of bright iron or steel.

When very great hardness is required, for which the heat indicated by this colour even would let down the temper to too great an extent, a bath of oil or tallow, or of some fusible alloy, affords a ready means of tempering. Lower tempers can also be given in the same way. The smoke from hot tallow or oil will be found convenient in enabling the degree of heat to be estimated ; the first slight smoke corresponding to straw colour, an abundant dark smoke to brown, and a very abundant black smoke to purple, in the list of colours given in the Appendix. By continuing the heating till the grease inflames and continues to burn, a still lower temper can be given. This method is known as 'blazing off,' and is much used for tempering springs.

Annealing reduces steel to its softest and most uniform condition, its effect being in fact just the opposite of hardening. It is often desirable in the case of tools, such, for instance, as those which admit of being shaped cold before hardening. As a remedy for the hardening effect of cold hammering or cold rolling, it is also had recourse to. And in turning or planing steel the life of the tools used upon it is greatly increased if it has been thoroughly annealed. The unequally hard condition, known amongst workmen as 'pinny' steel, may also generally be remedied by annealing.

Steel can be annealed by simply allowing it to cool slowly after moderate and uniform heating. To retard the cooling, it is sometimes buried in lime or in ashes on being withdrawn from the fire. Heating in a box of charcoal, and leaving it in the box till cool, is recommended for small articles ; but in annealing steel, as in all stages of its treatment, continued heating, after the full heat has once been reached, is very prejudicial. If much prolonged, it may even leave the steel more harsh and brittle than it was before.

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Partial annealing takes place when steel is heated to a point below its hardening temperature, and is then cooled in water.

Toughening steel, by heating it uniformly and quenching it in oil, has been found to improve both its strength and workability. More especially does it do so in the case of thick masses, of which both the elastic limits and the power of resisting tensile strain may thus be greatly extended. The impossibility of submitting such masses to the hardening and tempering processes just described, owing to the former being almost confined to the neighbourhood of the surface, renders this method of treating them doubly valuable.

The question—What occurs when steel is hardened and tempered? is one to which the reader may not improbably be anxious to find an answer here. We are sorry to be obliged to disappoint him. Although these valuable properties of steel, which are not shared by any other available substance, have been known for centuries, there is still no theory accepted as a satisfactory explanation of them. That the structure undergoes a change in hardening, and a still greater change in 'burning,' is at once evident on breaking a steel bar which has been so treated—as is shown by the fractures of annealed, hardened, and burnt steel in Fig. 282, which are engraved from a beautiful photograph taken 'from life.' And it appears to be certain that hardening induces a state of internal strain which is greater or less in proportion to the bulk of the steel and the degree of heat to which it has been subjected. But the causes of all these changes require careful further investigation.

Some of the points, however, which have been noted above, in connection with heating, appear to admit of explanation, if—as the writer believes—either steel itself, or some compound of iron and carbon contained in it, shares with the generality of metals a strong tendency to crystallise, and if the granular structure which it thus assumes

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diminishes cohesive strength. In the cold of course this structural change cannot take place at all, or can only do so very slowly, but the change immediately commences on heating, and the higher the heat and the longer the time of its continuance, the larger and the less coherent will be the crystals formed. Overheating or soaking in the fire will thus weaken the structure more or less according to the extent to which it has been carried finally giving 'burnt' steel, of which the cohesion between the grains is so far destroyed that a very slight shock or strain is sufficient to tear them asunder.

Annealed. Hardened. Burnt.

FIG. 282.—Fractures of Steel.

Working steel whilst soft on the other hand, will tend to reduce the size of the grains or crystals, just as—to adopt the simile suggested by M. Chernoff—shaking or stirring will affect those of a crystalline salt during their deposition from a saturated solution. It will therefore, conduce to obtaining the steel in its strongest condition, as we know that it does. Continuous hammering till a black heat is reached is the usual practice of tool-smiths, and it probably is partly in this manner that it imparts fineness of grain, which it does more especially at the surface; though it is doubtless of service also through its increasing the density by closing the pores of the steel, as in the case of any other metal which can be 'hammer hardened.'

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The strictly defined limit to the action of temperature in changing the structure of steel, or otherwise affecting it when it is locally heated, is remarkable. It appears to give rise to the locally weakened cohesion to which allusion has been made as a source of failure in hardening, and also not unfrequently to fracture in use, even when a tool has been hardened successfully, without any appearance of water-cracks.

The sketch, Fig. 283, shows a mishap with which most users of chisels are familiar, in which the form of the breakage (which occurred during use), lends strong probability to its having been caused by a structural change due to a dif-

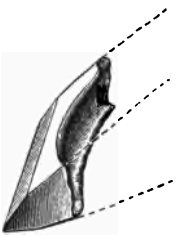

FIG. 283. —Broken Chisel.

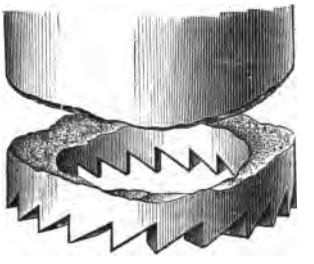

FIG. 284.—Broken Cutter.

ference of temperature on the two sides of the fracture. And a similar tale appears to be told by the cutter shown in Fig. 284, which actually parted in hardening. This interesting example, kindly lent by the late Mr. Jabez James to illustrate this subject, was one of a very few failures out of a large number of similar cutters. The few cracks which did occur, took in every case the same direction as the fracture shown in the engraving.

From what has been said respecting the different temperatures and treatment generally to which different kinds of steel must be subjected, in order to bring them to the most durable condition, it will be easily understood that it

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is well in practice to limit rather than to extend the number of kinds employed in an engineer's workshop. By adhering to two or three kinds, the niceties of their treatment become known to a tool-smith, and he can obtain uniformly good results with a certainty which can scarcely be expected of him under other circumstances.

It may, however, often be advantageous to use one or other of the various kinds of *special steel* which are to be met with. The name usually indicates that some other substance besides carbon has been intentionally introduced in the process of manufacture. Amongst these may be mentioned :—

Mushet's special steel, which has the peculiarity of not losing its temper by the heat generated in turning, &c. It can be forged at a moderate heat, and in cooling returns to its former or to a greater hardness, so that no subsequent hardening or tempering is required. For cutters liable to heat in working, or for punches used for hot materials, this property is a valuable one.

Styrian special steel, which is said to contain 23 parts of carbon in 1000, and a high percentage of manganese. When hardened, this steel shows a fracture which can scarcely be surpassed for fineness and uniformity of grain, and it appears to possess great power of endurance. Styria has the advantage of abundant vegetable fuel, and as this is used throughout the manufacture it conduces greatly to the purity of the steel, of which various qualities and degrees of temper are now obtainable in this country.

As a practical guide towards choosing good tool-steel, Mr. Ede gives the following workshop test. Forge a diamond-pointed chisel ; harden it carefully, and temper it to a violet colour ; grind it, and use it upon a piece of hard cast iron. If it will resist the blows of the hammer without breaking and will keep a sharp firm edge, full reliance may be placed on the quality of the steel.

For a like purpose, he recommends drawing out a piece of the steel to a fine point—with the usual precautions—

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hardening it fully, and testing—first, the hardness of the point, by its power to scratch glass; secondly, the tenacity, by breaking off a small piece of the hardened end, placing it on a block of hard cast iron, and striking it with a light hard-faced hammer. If the steel is good, the fragment will cut the hammer face and will bury itself in the cast iron, but, if inferior, it can in this way be either crushed flat or ground to powder.

Steel in general will endure working at low heat or in the cold better than iron will, and it may even be improved by it, as already mentioned. But some kinds of impure steel will break in a remarkable way if it is attempted to bend them whilst warm, though either in the cold or at a red heat they may be bent without injury. This has been indisputably proved in the case of shipbuilding plates and bars.

Thus far we have been dealing with the treatment of steel cutting tools when we call in to our aid the action of heat. But further treatment in the cold is almost invariably necessary in the case of the tools which have been subjected to the hardening and tempering processes above described, and for many others cold treatment is preferred on account of the greater certainty of its results.

Hard steel can be effectively cut or abraded only by substances harder than itself. This limits to a comparatively few the number of minerals at our disposal for the purpose, and excludes the whole of the metals and alloys at present known to us. Indeed, so far as edge tools possessed of sufficient endurance for cutting hardened steel are concerned, it may be said that we are not acquainted with any practically available substance from which to make them. Diamond flakes may be so employed in some few instances, but, even if the cost of such tools was not prohibitory, their brittleness and incapability of enduring the heat generated in working would unfit them for use, except on a minute scale. Indirectly, however, as we shall pre-

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sently see, the diamond gives valuable assistance in the working of steel.

We are thus driven to depend almost wholly on abrasive substances, some of which, such as the silicious stones used for grindstones and hones, occur in nature ready to our hand. The hones have already been sufficiently noticed in Chapter II., but it will be well to supplement here the short description of the grindstones which was given in connection with hand-tool grinding.

'Show me the grindstone, and I will tell you the character of the work which is turned out in the shop,' was the remark, based on many years of experience, of a late very eminent marine-engine builder. And the fact cannot be too strongly impressed—on machine workers and on hand workers alike—that with a bad or a badly-used grindstone ill-ground tools will be the rule, and with tools badly ground the work which is done will assuredly suffer, either in quality or in quantity, and most probably in both.

The method recommended for hanging a grindstone intended for the ordinary service of a fitting shop is shown in Fig. 285.

The stone—which is usually from two to four feet in diameter and from four to eight inches thick—is firmly clipped between two circular cast-iron plates, between each of which and the stone surface there is introduced a thin piece of soft wood 'packing,' which accommodates itself to any slight irregularities, and gives the plates a firm grip. The spindle runs in plummer-blocks fixed on the two sides of the cast-iron water-trough, and is provided with an ordinary fast and loose pulley. The trough also carries at one end a wrought-iron rest, adjustable as to height, with the assistance of which, as long as the stone runs true, tools can be ground by a practised hand in a very efficient manner. But no sooner does the grindstone lose its circular form than the rest becomes worse than useless ; and this is always liable to happen, either through careless use, or through one

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part becoming softened by being left standing in the water. And when once the evil has commenced it will go on increasing, until it is remedied by turning the face of the stone —either dry, with a steel point, in the manner already described, or with some form of *grindstone dresser*, of which one or two different patterns have been introduced, to obviate the necessity for that dusty and unpleasant operation.

Even when the condition of the grindstone is perfectly satisfactory, the correctness of the angles which the facets of a cutting edge ground upon it form with each other and with

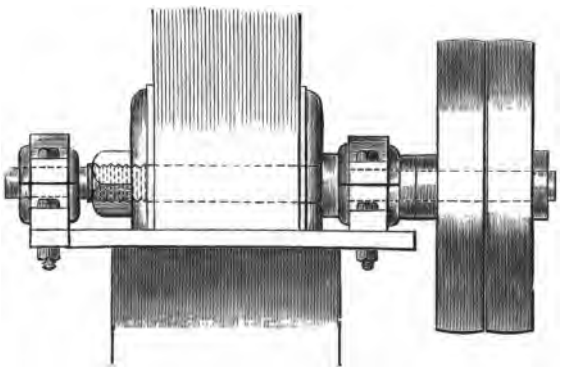

FIG. 285.—Method of hanging Grindstone.

the shank of the tool, depends entirely upon the skill of the operator, although of course he may, and in general he should, have the assistance of a gauge or template. But either with this or without it, very great advantages will almost always be found to accrue from the adoption of the system of Machine Grinding introduced by Sir Joseph Whitworth. Fig. 286 shows one form of his apparatus for the purpose, which is in fact an application of the slide principle to the grinding of tools. Instead of the fixed rest mentioned above, the end of the trough is made to carry a

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slide-rest, of which the cross-slide is driven by a screw in the ordinary way, and the lower slide by a rack and pinion. By working the handle attached to the pinion, the tool (when its extremity is being ground) can be easily kept in motion,

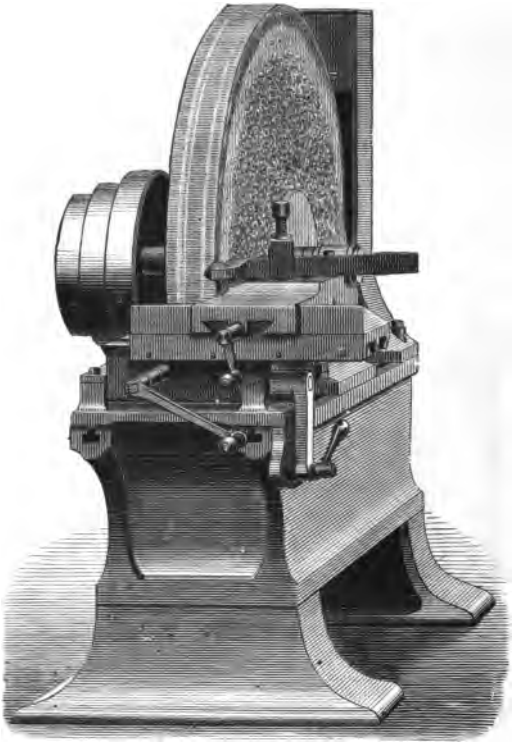

FIG. 286.—Grindstone with Slide-rest.

so that all scoring and grooving of the face of the stone are prevented. The required angle can be given with unfailing certainty by a single adjustment of the rest, the entire body of which is hinged to the trough for this purpose. Perfect

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uniformity in the angles of any number of tools can thus be obtained, and they can be ground not only more rapidly, but in a very superior manner. Moreover, all unequal wear of the stone is prevented, so that the process of turning it up need never be resorted to. The speed at which the face of the stone is driven is about 830 feet per minute.

The facet produced in grinding a tool in this manner is of course concave or 'hollow,' more or less according to the diameter of the grindstone. When this hollowness is objectionable, it can be avoided by using the side instead of the cylindrical face of the stone; for doing which *Surface Grindstones* are specially arranged, with slide-rests of which the traverse is at right angles to the spindle, instead of parallel to it as in Fig. 286. From such stones the portion near the spindle, which is comparatively inert on account of its slow speed, is cut away before they are mounted, so that only a wide annular face remains.

The overhanging end of a grindstone spindle is sometimes utilised by fixing upon it an annular hone, made up of segments of Water of Ayr stone, mounted on a cast-iron disc. This affords a ready means of 'setting' the edges of tools which have been ground, and is especially useful in the case of wood-working tools.

But by far the largest class of grinding machines, and one which lends itself to many purposes for which natural grindstones are ill-suited, is that of the *Emery Grinders*, to which allusion has already been made. In these machines artificial Emery wheels, which can be varied as required in respect of diameter, thickness, and coarseness of grain, are run at a very high rate of speed, especial attention being paid to their truth and steadiness. Under these conditions they abrade even the hardest steel with an avidity which far exceeds that of the natural grit stones; whilst at the same time they themselves become worn away to a far less extent. They can thus be used for delicate grinding operations, such as cutting the grooves of a screw-tap or a rimer, which

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would be very difficult, if not impossible, with a natural grindstone.

Although artificial wheels made with corundum or emery are a very old device, being said to have been used in India and China for centuries, it is recently only that they have found much favour in this country. One main reason for this seems to have been, that as long as the Eastern practice was followed and lac and other fusible substances were used as the cementing materials, the wheels were incapable of standing the heat generated in grinding at the high speed which is essential for obtaining their full effect. The cohesive strength of such materials, moreover, was probably insufficient to prevent their flying to pieces from the centrifugal force, if high speeds were attempted.

Most of the modern *Emery Wheels* are free from these objections. America—ever ready to adopt labour-saving processes—took the lead in improving the manufacture both of the wheels and of the machines in which to use them, and this country, following somewhat tardily in her steps, now both produces and uses them on an extensive scale.

Emery wheels are ordinarily obtainable of any diameter up to 36 inches, and their usual thicknesses range from about $\frac{1}{4}$ inch for the smaller to 6 inches for the larger sizes; and these dimensions are capable of extension if necessary, though the cost of a wheel of very large size, or of very great thickness, becomes rather a serious consideration. The surface speed recommended for them varies with different manufacturers from about 2,000 to 6,000 feet per minute for wheels of 6 inches diameter and upwards. The number of sizes of the grain or 'grit' also varies, three—'coarse,' 'medium,' and 'fine'—being found sufficient by some makers, and others having as many as ten different 'grades.' The composition of the wheels can be made either 'soft' or 'hard,' according to the purpose for which they are required.

The machines in which these wheels are used present still

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greater variety of arrangement, their uses being many besides the tool-grinding which brings them more especially into the present branch of our subject. Fig. 287 shows the upper portion of a *General Emery Grinder* with two wheels, intended for tool-grinding by hand, or for any small grinding. The wheels supplied with this machine, in common with many, but not with all, of the kinds now in the market, can be used either wet or dry. Dry grinding, however, is often preferred; the chief objections to it being—first, the possibility of damage to the temper of a tool from its heating;

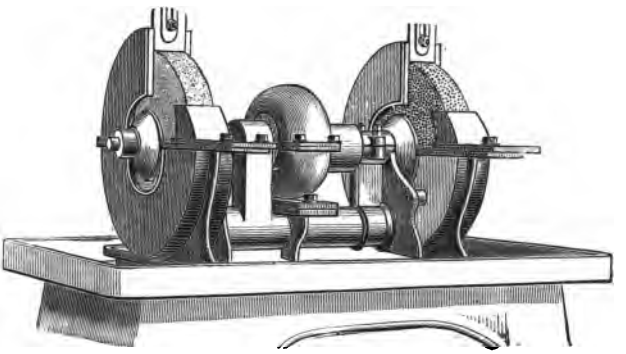

FIG. 287.—General Emery Grinder.

secondly, the dust, which is liable to be injurious to any one continually inhaling it, and causes undue wear of all neighbouring journals or slides into which it finds its way. In the machine represented in Fig. 287, however, the second of these objections is obviated by mounting a fan on the spindle between the wheels, and so connecting it with the wheel casings as to set up an in-draught of air, which carries off the dust. And in wet-grinding, the fan carries off the spray. 12-inch emery wheels are intended to be driven in this machine at a rate of 1,600 revolutions per minute.

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The liability to accident from emery wheels flying to pieces through the powerful centrifugal force which is inseparable from the high speeds which they require is much diminished by mounting them between large iron washers, of which the diameter should in each case be fully one-half that of the wheel. These should be tightly clipped together, either with through bolts, or with a nut on the spindle (as in Fig. 285), soaked paper or some other yielding material being inserted between them and the wheel. On the same account care should be taken that the wheel does not fit tightly on the spindle.

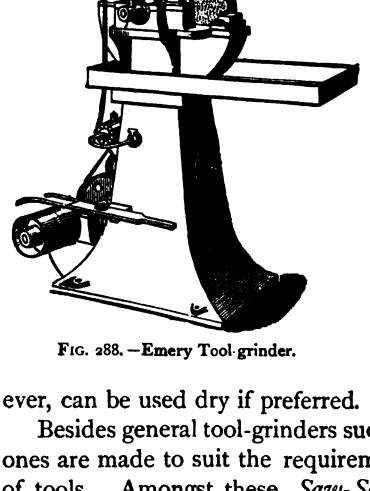

FIG. 288.—Emery Tool-grinder.

An *Emery Tool Grinder*, differently arranged, and with a rather larger wheel than the previous one, is shown in Fig. 288. In this case the pedestal forms a tank, from which a small centrifugal pump throws a continuous supply of water on to the face of the wheel, which, however, can be used dry if preferred.

Besides general tool-grinders such as these, various special ones are made to suit the requirements of particular classes of tools. Amongst these *Saw-Sharpening Machines* were some of the first to come into general use, the costly process of hand-filing, by which saw-teeth were previously sharpened, being one which stood in great need of improvement, especially in the case of machine saws. The 'gulleting' or 'gumming' of these or any other saws with gullet-teeth can be very quickly done in these machines, thin emery wheels being used, with which the gullet can be

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cut down to any desired depth. 'Topping' also can be done with the same wheel differently applied.

Twist-Drill Grinders enable the true spiral form to be given to the cutting end of a twist-drill, which it is not easy to give in grinding by hand.

Tap Sharpening Machines have small emery wheels suitably mounted for cutting or re-cutting the longitudinal grooves of screw-taps and rimers, which they readily accomplish, however hard may be the temper of the steel.

The following emery-grinders also should not be passed over without mention, though their duties are by no means confined to the working of steel.

Emery Planers, in which the work travels to and fro on a sliding table beneath a revolving emery wheel, to which it is fed up as required.

Surface Grinders, which enable the same system to be applied to larger articles than planers can accommodate. In some of these the guidance is merely given by hand to the revolving wheel, which is mounted on a jointed frame suspended from the roof. Others have a small planed table with a central opening, through which a very small and adjustable portion of the top of the wheel projects. The work is laid face downwards on the table, and moved about so as to bring each part in succession over the wheel. By providing the table with a simple 'fence,' like that of a circular saw-bench, a machine of this kind can also be used for running grooves or mouldings, with emery wheels of suitable form.

For *Emery-Copying and Edge-Grinding Machines* many uses will suggest themselves. The emery wheel, which for plain grinding is small and thick, is in some of these machines placed horizontally almost in the centre of a rather large-sized table, through which it can be made to rise and fall slowly to a sufficient extent to ensure its wearing equally. The edge of any piece of work which can be accommodated on the table can then be fed up to the edge

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of the wheel, the guidance being given either by hand or by a template attached to the work and kept in contact with a 'feeler' fixed above the wheel, and corresponding with it in diameter. In running edge mouldings with these machines the moulded emery wheel is of course kept at one uniform height.

These examples, which might easily be multiplied, will suffice to give a general idea of the capabilities of this large and growing class of machine tools. Moreover, the use of emery wheels is not always confined to purposes which entail the adoption of specially constructed machines. A small wheel may be simply mounted on a *lathe attachment* capable of being carried by a slide-rest, and may thus form a highly effective substitute for ordinary lathe tools in some kinds of work. Hardened steel, chilled iron, or iron castings with their harsh gritty skin unremoved can thus be turned, all of these being powerless to resist the abrading power of emery, though they would rapidly destroy cutting edges made of steel.

FIG. 289.—Carbonates or Black Diamonds.

The abrasive properties of loose sand have lately been turned to account in an ingenious and, it is said, a very successful way, by the application of Tilghman's sand-blast process to the sharpening of file-teeth, of which the edges can thus be re-formed without lowering their temper.

But hand-filing is now being completely superseded by emery grinding in several branches of manufacture which entail the frequent reproduction of complex forms in iron or steel, the result being that a previously unattainable uniformity is secured, and at a small fraction only of the former cost. In short, it may be said that the system places at our disposal a more effective method than any which we have hitherto possessed for asserting our mastery

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over some of the most refractory of all the natural substances which we press into our service.

The necessity for maintaining the true cylindrical form of a grindstone has already been insisted on. The need is even greater in the case of emery wheels, but their superior hardness makes it difficult to shape them with a steel tool of any kind. Recourse is therefore had to the hardest

FIG. 290.—Hand Diamond Tool.

known substance, the diamond; the opaque black variety found in Brazil—where it is known as 'carbonado' (carbonate)—being preferred to the crystalline form used for gems and for glass-cutting. Some good angular specimens of this amorphous *Carbonate*, three or four times the size of the pieces which would ordinarily be used, are represented in Fig. 289. And in Figs. 290 and 291 are shown, full size, two such diamonds mounted in soft iron or steel for use as a *hand tool* and as a *slide-rest tool* respectively. Their use requires care, and very light cuts should only be attempted with them—especially with the latter, when it is grasped in the unyielding iron hand for which it is intended. And in either case the emery wheel should be run at a low speed only whilst it is being turned. When these simple precautions are attended to, it will be found, wherever emery grinders are used, that a diamond tool forms one of the most useful of all workshop appliances.

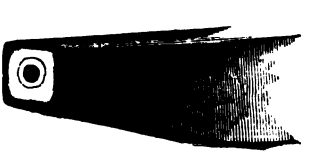

FIG. 291.—Diamond Tool for Slide-rest.

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APPENDIX.

Colours in Tempering Steel.

		Fahr.
Very pale straw yellow	for tools and cutters for metal	430°
A shade of darker yellow		450°
Darker straw yellow	for edge-tools, taps, &c.	470°
Still darker straw yellow		490°
Brown yellow	for saws, hatchets, &c.	500°
Yellow tinged with purple		520°
Light purple		530°
Dark purple	for springs	550°
Dark blue		570°
Paler blue	too soft for the above purposes	590°
Still paler blue	,, ,, ,,	610°
Still paler blue with tinge of green	,, ,, ,,	630°

Wire Gauge, Board of Trade Standard.

Descriptive Number	Equivalents in parts of an inch	Metric equivalent in millimètres	Descriptive Number	Equivalents in parts of an inch.	Metric equivalent in millimètres
No. 7/0	0·500	12·700	No. 23	0·024	0·610
6/0	·464	11·785	24	·022	·559
5/0	·432	10·973	25	·020	·508
4/0	·400	10·160	26	·018	·457
3/0	·372	9·449	27	·0164	·4166
2/0	·348	8·839	28	·0148	·3759
0	·324	8·229	29	·0136	·3454
1	·300	7·620	30	·0124	·3150
2	·276	7·010	31	·0116	·2946
3	·252	6·401	32	·0108	·2743
4	·232	5·893	33	·0100	·2540
5	·212	5·385	34	·0092	·2337
6	·192	4·877	35	·0084	·2134
7	·176	4·470	36	·0076	·1930
8	·150	4·064	37	·0068	·1727
9	·144	3·658	38	·0060	·1524
10	·128	3·251	39	·0052	·1321
11	·116	2·946	40	·0048	·1219
12	·104	2·642	41	·0044	·1118
13	·092	2·337	42	·0040	·1016
14	·080	2·032	43	·0036	·0914
15	·072	1·829	44	·0032	·0813
16	·064	1·626	45	·0028	·0711
17	·056	1·422	46	·0024	·0610
18	·048	1·219	47	·0020	·0508
19	·040	1·016	48	·0016	·0406
20	·036	0·914	49	·0012	·0305
21	·032	·813	50	·0010	·0254
22	·028	·711			

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TABLE I.

Comparison of the Numbers of the Standard Decimal Gauge with those of the Birmingham Wire Gauge, &c.

Decimal Gauge (Thousandths of an inch)	Corresponding Numbers of the Old			Decimal Gauge (Thousandths of an inch)	Corresponding Numbers of the Old		
	Birmingham Wire Gauge	Birmingham Plate Gauge	Lancashire Gauge		Birmingham Wire Gauge	Birmingham Plate Gauge	Lancashire Gauge
1	...			50	18	16	55
2	...			55	...	17*	54
3	...			60	17*	18	52**
4	36	1		65	16	19	51
5	35	2		70	15*	21*	49*
6	...	...		75	...	22	47*
7	34	...		80	...	24*	45
8	33	3		85	14*	...	43**
9	32	...		90	...	...	42
10	31	4		95	13	25	41
11	...	...		100	...	26**	38
12	30	5		110	12	27**	34
13	29	6	80	120	11	28	31*
14	28	...	79	135	10	31*	29
15	...	7	78	150	9*	34*	23**
16	27	8	77	165	8	36*	19
17	...	...	...	180	7	...	13*
18	26	...	76	200	6**	...	5**
19	...	9	...	220	5	...	2
20	25	...	75	240	4*	...	C*
22	24	...	74	260	3	...	G
24	23*	10	72	280	2**	...	K
26	...	...	71	300	1	...	N*
28	22	11	70	325	...	...	P*
30	...	...	68	350	...	...	S*
32	21	...	66	375	00**	...	V*
34	...	12	64	400	...	...	X**
36	20	13	62	425	000		
38	...	...	61	450	0000**		
40	19*	14	59	475			
45	...	15*	56	500			

NOTE.—Sizes which differ from those in the first column by more than ·002 of an inch are marked thus ** ; those of which the difference exceeds ·001, thus *. All others either correspond exactly, or are within ·001 of an inch.

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TABLE II.

Belgian Zinc Gauge.

No.	1	2	3	4	5	6	7	8	9	10	11	12
Approximate thickness in decimals of an inch	·002	·004	·006	·008	·010	·012	·014	·016	·018	·020	·023	·026
Ditto in millimetres	·05	·10	·15	·20	·25	·30	·35	·40	·45	·50	·58	·66

No.	13	14	15	16	17	18	19	20	21	22	23	24	25	26
In.	·029	·032	·037	·043	·048	·053	·058	·063	·070	·077	·0 4	·091	·098	·105
Mm.	·74	·82	·95	1·08	1·21	1·34	1·47	1·60	1·78	1·96	2·14	2·32	2·50	2·68

NOTE.—Ordinary 'roofing thicknesses' are from No. 13 to No. 18.

TABLE III.

Sizes and Weights of Tin Plates.

Mark	Name	No. in each box	Size in inches	Weight of each box		
				cwt.	qrs.	lbs.
CI	Common No. 1	225	$13\frac{3}{4} \times 10$	1	0	0
CII	Common No. 2	,,	$13\frac{1}{4} \times 9\frac{3}{4}$	0	3	21
C III	Common No. 3	,,	$12\frac{3}{4} \times 9\frac{1}{2}$	0	3	16
X I	Cross No. 1	,,	$13\frac{1}{4} \times 10$	1	1	0
XX I	Two Cross No. 1	,,	,,	1	1	21
XXX I	Three Cross No. 1	,,	,,	1	2	14
XXXX I	Four Cross No. 1	,,	,,	1	3	7
CD	Common Doubles	100	$16\frac{3}{4} \times 12\frac{1}{4}$	0	2	21
XD	Cross Doubles	,,	,,	1	0	14
XXD	Two Cross Doubles	,,	,,	1	1	7
XXXD	Three Cross Doubles	,,	,,	1	2	0
XXXXD	Four Cross Doubles	,,	,,	1	2	21
CSD	Common Small Doubles	200	15 × 11	1	2	0
XSD	Cross Small Doubles	,,	,,	1	2	21
XXSD	Two Cross Small Doubles	,,	,,	1	3	14
XXXSD	Three Cross Small Doubles	,,	,,	2	0	7
XXXXSD	Four Cross Small Doubles	,,	,,	2	1	0
WC	Wasters, Common No. 1	225	$13\frac{3}{4} \times 10$	1	0	0
WX I	Wasters, Cross No 1	,,	,,	1	1	0

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Tables of Whitworth's Screw Threads.

TABLE IV.

Engineers' angular-threaded screws.

Diameter inches	Threads per inch
1/32	150
1/16	80
3/32	60
1/8	40
5/32	32
3/16	24
7/32	,,
1/4	20
5/16	18
3/8	16
7/16	14
1/2	12
9/16	11
5/8	10
7/8	9
1	8
1 1/8	7
1 1/4	,,
1 3/8	6
1 1/2	,,
1 5/8	5
1 3/4	,,
1 7/8	4½
2	,,
2 1/4	,,
2 1/2	4
2 3/4	,,
3	,,
3 1/4	3½
3 1/2	,,
3 3/4	3
4	,,
4 1/4	2⅞
4 1/2	,,
4 3/4	2¾
5	,,
5 1/4	2⅝
5 1/2	,,
5 3/4	2½
6	,,

TABLE V.

Small Screws. (Proposed.)

Diameter. Thousandth of an inch	Threads per inch
10	400
11	,,
12	350
13	,,
14	300
15	,,
16	,,
17	250
18	,,
19	,,
20	210
22	,,
24	,,
26	180
28	,,
30	,,
32	150
34	,,
36	,,
38	120
40	,,
45	,,
50	100
55	,,
60	,,
65	80
70	,,
75	,,
80	60
85	,,
90	,,
95	,,
100	50

TABLE VI.

Iron Gas Piping.

Inches Diameter. Inside	Inches Diameter. Outside	Threads per inch
1/16	·38	28
1/8	·52	19
3/16	·66	,,
1/4	·82	14
5/16	1·03	,,
1	1·30	
1 1/16	1·49	
1 1/8	1·65	
1 3/16	1·74	
1 1/4	1·88	
1 5/16	2·02	
1 3/8	2·04	
1 7/16	2·24	
2	2·34	
2 1/16	2·46	
2 1/8	2·58	11
2 3/16	2·79	
2 1/4	3·00	
2 5/16	3·12	
2 3/8	3·24	
2 7/16	3·36	
3	3·48	
3 1/16	3·69	
3 1/8	3·92	
3 3/16	4·12	
4	4·33	

TABLE VII.

Hydraulic Piping.

Inches Diameter. Inside	Inches Diameter. Outside	Threads per inch
1/4	3/8 to 1	14
3/8	3/4 to 1 1/8	,,
1/2	1 or 1 1/4	,,
,,	1 1/4 or 1 3/8	11
5/8	1 5/8	14
,,	1 1/4 to 1 1/2	
3/4	1 1/2 to 1 5/8	
7/8	1 3/4 to 1 7/8	
1	1 7/8 to 2	
1 1/4	1 1/2 to 2 1/4	
1 1/2	1 3/4 to 2 1/2	11
1 3/4	2 to 2 3/4	
1 7/8	2 1/4 to 2 3/4	
1 1/2	2 1/2 to 2 3/4	
1 7/8	2 3/4 to 2 7/8	
2	2 1/2 to 3	

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TABLE VIII.

Table of Change Wheels for Screw-cutting Lathe, with Leading Screw of Three Threads to an Inch.

(*Number of Wheels required* = 18.)

No. of Threads per inch	Left-Hand Screws				Right-Hand Screws.				
	Lathe-spindle	Stud	Stud	Leading Screw	Lathe-Spindle	Stud	Stud	Stud	Leading Screw
1	30	80	**20, 60**	30	30	35	40	**20, 60**	30
1½	,,	75	**20, 60**	45	,,	40	30	**20, 60**	45
2	,,	60	70	20	,,		120		20
2½	,,	50	70	25	,,		120		25
2⅝	,,	80	**35, 40**	30	,,	50	25	**35, 40**	30
2¾	,,	50	**55, 60**	30	,,			**110, 120**	30
2⅛	,,	60	**23, 40**	50	,,	50	35	**23, 40**	50
3	,,	50	65	30	,,		110		30
3¼	,,	70	**25, 50**	65	,,	40	20	**25, 50**	65
3½	,,	50	65	35	,,		110		35
4	,,	50	60	40	,,		110		40
4½	,,	50	60	45	,,		110		45
5	,,	45	60	50	,,		110		50
6	,,	45	55	60	,,		100		60
7	,,	50	45	70	,,		90		70
8	,,	50	45	80	,,		90		80
9	,,	50	40	90	,,		80		90
10	,,	50	35	100	,,		80		100
11	,,	50	25	110	,,		70		110
12	,,	50	25	120	,,		70		120
14	,,	65	**35, 20**	80	,,			**70, 60**	120
16	,,	60	**40, 20**	80	,,			**80, 60**	120
18	,,	60	**45, 20**	80	,,			**90, 60**	120
20	,,	60	**50, 20**	80	,,			**100, 60**	120
24	,,	50	**60, 20**	80	,,			**80, 40**	120

NOTE.—The wheels of which the number of teeth in the above table are in thick type only need be adhered to. For the others, which are idle wheels, any which can be got in may be substituted.

Where two numbers occur in one column the wheels are to be connected together, and work on the same stud, the second one gearing with the wheel on the leading-screw.

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